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Functional Textile Socks in Rheumatoid Arthritis or Psoriatic Arthritis: A Randomized Controlled Study

Kirkke Reisberg [1,*], Kristiine Hõrrak [2], Aile Tamm [3], Margarita Kõrver [1], Liina Animägi [1] and Jonete Visnapuu [1]

[1] Department of Physiotherapy and Environmental Health, Tartu Applied Health Sciences University, 50411 Tartu, Estonia; margaritakorver@nooruse.ee (M.K.); liinaanimagi@nooruse.ee (L.A.); jonete.visnapuu@gmail.com (J.V.)
[2] Hortus Medicus LLC, 10621 Tallinn, Estonia; kristiine.horrak@hortusmedicus.ee
[3] Institute of Physics, University of Tartu, 50411 Tartu, Estonia; aile.tamm@ut.ee
* Correspondence: kirkkereisberg@nooruse.ee

Abstract

There is limited knowledge about the benefits of functional textile in arthritis management. This study aimed to evaluate the effect of wearing functional socks in patients with rheumatoid or psoriatic arthritis. Patients were randomized into an experimental group (n = 23) and control group (n = 18). The intervention involved wearing functional textile socks for 12 weeks. Sock composition was analyzed using X-ray fluorescence spectrometry and scanning electron microscopy. Outcome measures included the Numeric Rating Scale, Health Assessment Questionnaire–Disability Index (HAQ-DI), and RAND-36 (Estonian version). At week 12, the experimental group showed significantly lower metatarsophalangeal and toe joint pain (p = 0.001), stiffness (p = 0.005), and ankle stiffness (p = 0.017) scores than the control group. Improvements were also observed in HAQ-DI reaching (p = 0.035) and activity (p = 0.028) scores. RAND-36 scores were higher in physical functioning (p = 0.013), social functioning (p = 0.024), and bodily pain (p = 0.006). Role limitations due to physical problems improved in the experimental group but worsened in the control group (p = 0.029). In conclusion, wearing functional socks led to some statistically significant improvements in foot and ankle pain and stiffness, physical function, and health-related quality of life. However, the effect sizes were small, and the clinical relevance of these findings should be interpreted with caution.

Keywords: functional textile socks; pain; function; quality of life; rheumatoid arthritis; psoriatic arthritis

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1. Introduction

Rheumatoid arthritis (RA) is the most common autoimmune inflammatory joint disease worldwide [1]. Psoriatic arthritis (PA) is also a chronic inflammatory disease that affects 0.04–0.1% of the general population [2] and 20–30% of patients with psoriasis [2,3]. The inflammation present in both RA and PA can lead to joint damage [4,5], resulting in functional impairment [4,5], pain [6,7], stiffness [8], and a decrease in quality of life [9,10].

Autoimmune joint diseases cannot be prevented, but inflammation and symptoms can be addressed. Reducing joint pain in individuals with inflammatory joint diseases and improving function would enhance the quality of life of those suffering from the disease, helping them continue to actively participate in the workforce and society for a longer period [11]. There are functional textiles that have been developed for medical, performance, and recovery improvement purposes, from which braces [12,13], gloves [14,15], underpants [16,17], undershirts and short-sleeve shirts [16], shorts, pants, leggings [16,18,19], blankets [20], and socks [16] are made. Functional textiles are fabrics designed with integrated features that fulfill specific end-use needs, in addition to their primary function [21], and they are considered a key area in both the textile industry and textile materials science [22].

Previously, the effect of the Incrediwear Cred 40 knee brace, which contains carbonized charcoal and germanium (Ge), was investigated in patients with osteoarthritis. The study found that this knee brace had a more favorable effect on patients with stage 1 or 2 osteoarthritis compared to those with stage 3 or 4 [12]. In another study, the effectiveness of the same Ge- and carbon-infused knee sleeve was compared to a combined treatment involving extremely low-frequency electromagnetic fields (intensity: 100 μT) in patients with knee osteoarthritis. The combined therapy showed superior outcomes in terms of pain relief at rest and functional recovery during follow-up [13]. However, since both studies [12,13] were nonrandomized and lacked a control group wearing a knee sleeve without bioactive elements, it is impossible to conclude how much of the effect was due to the possibility that the improvements demonstrated by the experimental group resulted from a placebo effect.

Additionally, to the best of our knowledge, the influence of functional textile socks in RA and PA has not been studied yet. Therefore, the purpose of the current randomized controlled study was to investigate whether wearing functional textile socks has an effect on ankle and foot joint pain and stiffness, physical function, and health-related quality of life in patients with RA and PA. More specifically, this study aimed to determine: (1) the effect of functional textile socks on the intensity of ankle, metatarsophalangeal, and toe joint pain and stiffness in RA and PA; (2) the effect of functional textile socks on physical function in RA and PA; (3) the effect of functional textile socks on health-related quality of life in RA and PA.

2. Materials and Methods

2.1. Study Organization and Participants

The study was conducted in Tartu Applied Health Sciences University, Estonia, in 2021–2022. The participants were adults (aged $\geq$ 18 years) diagnosed with rheumatoid arthritis or psoriatic arthritis who had experienced foot pain and/or stiffness lasting for at least the past six months. Exclusion criteria for participation were: (1) malignant tumors, (2) a tumor or a skin lesion of unknown origin on the foot or shin.

Participants were recruited through the Estonian Rheumatism Association, the Estonian Psoriasis Association, the Rheumatology Centers of East Tallinn Central Hospital and West Tallinn Central Hospital, the Rheumatology Unit at North Estonia Medical Centre, The Internal Medicine Clinic of Tartu University Hospital, LLC The Foot Care Clinic, several family medicine centers, and media outlets such as local newspapers and social media portals (Facebook).

Consent for participation was obtained from 51 individuals, who were randomly assigned to two groups: the experimental group (n = 26), whose participants wore socks made of functional textile containing Ge and zirconium (Zr), which were not present in the control socks, as well as significantly higher concentrations of certain elements such as potassium (K), zinc (Zn), magnesium (Mg), titanium (Ti), chlorine (Cl), sulfur (S), and phosphorus (P); and the control group (n = 25), whose participants wore socks that were not made of functional textile. Both sock types contained some elements at comparable concentrations (i.e., calcium—Ca, silicon—Si, aluminum—Al, sodium—Na, iron—Fe). All modifications to the functional socks, including the incorporation of semiconductive metals, were made by the manufacturing company; the authors did not alter the textile composition. According to the Estonian Health Board's medical devices database, Incrediwear Ge-embedded socks (manufactured by Incrediwear Holdings, Inc., Chico, CA, USA) have been registered as a low-risk (Class I) medical device since 26 January 2018 (MSA code 11902, Estonian Medical Devices Register) [23]. Randomization was performed using the Research Randomizer software (version 4.0) [24]. Both participants and researchers were blinded to which group participants were assigned.

Ten participants discontinued the study. There was no significant difference between the experimental group (42.9%) and the control group (57.1%) in terms of discontinuation due to foot pain or worsening symptoms ($p = 0.729$). The final data analysis included 41 participants, with 23 in the experimental group and 18 in the control group.

The element concentration of socks was determined by an independent institute of measurements—the Department of Materials Science of the Institute of Physics at the University of Tartu—and the results were revealed to the study team after the completion of the experimental part of the study.

This study was approved by the Research Ethics Committee of the University of Tartu (references 345/T-23 and 362/M-2) and is consistent with the ethical standards of the Declaration of Helsinki.

2.2. Fiber Composition of the Socks

According to information from the sock manufacturer (Incrediwear Holdings Inc., Chico, CA, USA), the socks used by the experimental group contained Ge, while the socks used by the control group did not. As reported by the manufacturer, the fiber composition of the experimental group socks was as follows: 36% cotton (which contained Ge), 34% polyester, 26% nylon (which contained Ge), and 4% elastane. The fiber composition of the control group socks was as follows: 36% cotton, 34% polyester, 26% nylon, and 4% elastane.

The element concentration (mass%) of the socks was determined using an X-ray fluorescence spectrometer (XRF) (Rigaku ZSX-400, Rigaku, Tokyo, Japan) which allows the determination of the element concentration (mass%) of the sample. For XRF analysis, the sock sample was irradiated with primary short-wavelength (high-energy) X-rays, which generate secondary X-ray fluorescence radiation through interaction with the atoms in the sample. Chemical elements have their specific fluorescence emission spectra, which enable the determination of the elemental composition of the sample.

Tablets with a diameter of 40 mm and a thickness of 4 mm were pressed from the material of the experimental and control socks using a force of 20 tons (Figure 1).

X-ray fluorescence spectrometry revealed that the experimental sock sample contained Zr at 0.0111 m% and Ge at 0.0021 m%. The control sock sample was devoid of Zr and Ge. Additionally, the experimental sock sample had significantly higher levels of several other chemical elements (K, Zn, Mg, Ti, Cl, S, P) compared to the control sock sample (Table 1).

Table 1. Element composition of the socks (mass%), measured by X-ray fluorescence spectrometry.

Chemical Element	Test Sock	Control Sock
C	51.8	47.8
O	47.4	52.0
K	**0.342**	0.0058
Ti	**0.169**	0.0726
Zn	**0.0671**	0.0005
Ca	0.0425	0.0140
Mg	**0.0422**	0.0046

Table 1. *Cont.*

Chemical Element	Test Sock	Control Sock
Si	0.0333	0.0426
Cl	**0.0316**	0.0022
S	**0.0216**	0.0058
P	**0.0203**	0.0021
Zr	**0.0111**	-
Al	0.0049	0.0027
Na	0.0027	0.0218
Ge	**0.0021**	-
Fe	0.0014	0.0016

The chemical elements listed in bold are those whose content in the test sock was several times higher than in the control sock.

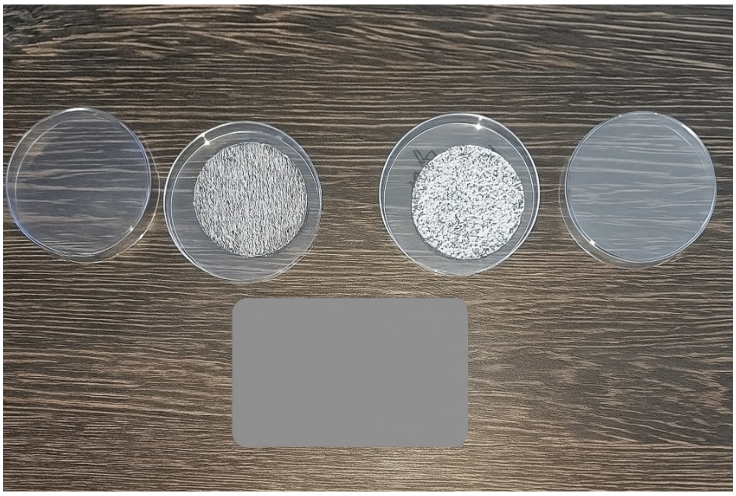

Figure 1. Preparation of the XRF measurement object—tablets pressed from the sock material (inside the sample holders). Bank card shown for size reference; identifying details removed.

2.3. Fiber Morphology of the Socks

To visually examine the surface morphology of the sock fibers, and the arrangement and texture of the fibers, a scanning electron microscope (SEM, FEI Helios™ NanoLab 600 DualBeam, FEI, Hillsboro, OR, USA) was used. For SEM analysis, smaller pieces were cut from the socks and attached to the SEM holder using double-sided carbon tape (Figure 2). To prevent charging under the electron beam, a very thin (8 nm) gold layer was sputtered onto the object's surface using a magnetron sputter coater, as the object was non-conductive. The accelerating voltage used for obtaining SEM images was 3 kV, and the electron beam current was 86 pA.

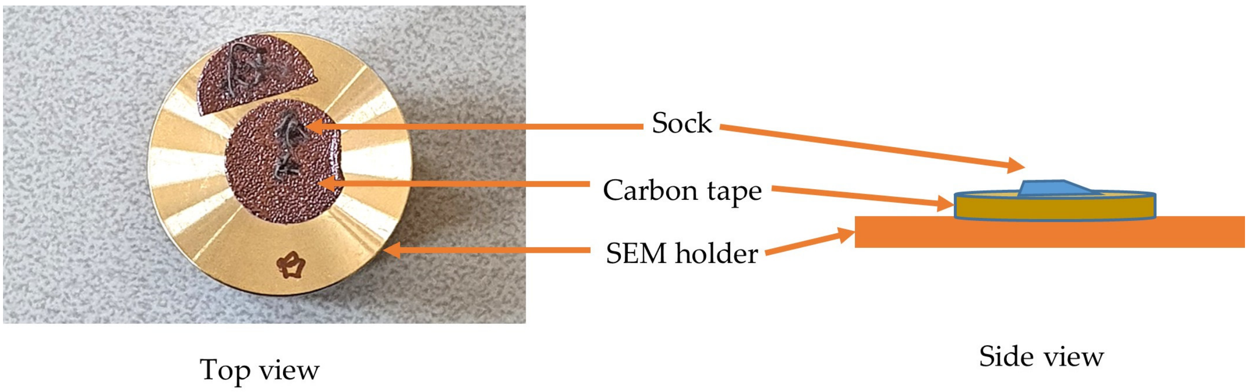

Figure 2. Samples prepared for SEM analysis.

SEM analysis showed that the samples consisted of fibers that were twisted into thicker bundles (Figure 3a,d) with an average diameter of 15 µm. Both samples contained two types of fibers. The first type of fiber resembled a ribbon with several twists, with a surface covered in fine grooves (Figure 3b,e) with an average diameter of 19 µm. This morphology is characteristic of cotton fibers. The second type of fiber was rod-shaped, with a uniform diameter and smooth surface (Figure 3c,f). This morphology is typical of synthetic fibers such as elastane and nylon. The fiber diameter was similar in both samples. SEM analysis did not detect significant differences in the morphology or diameter of the fibers between samples A and B.

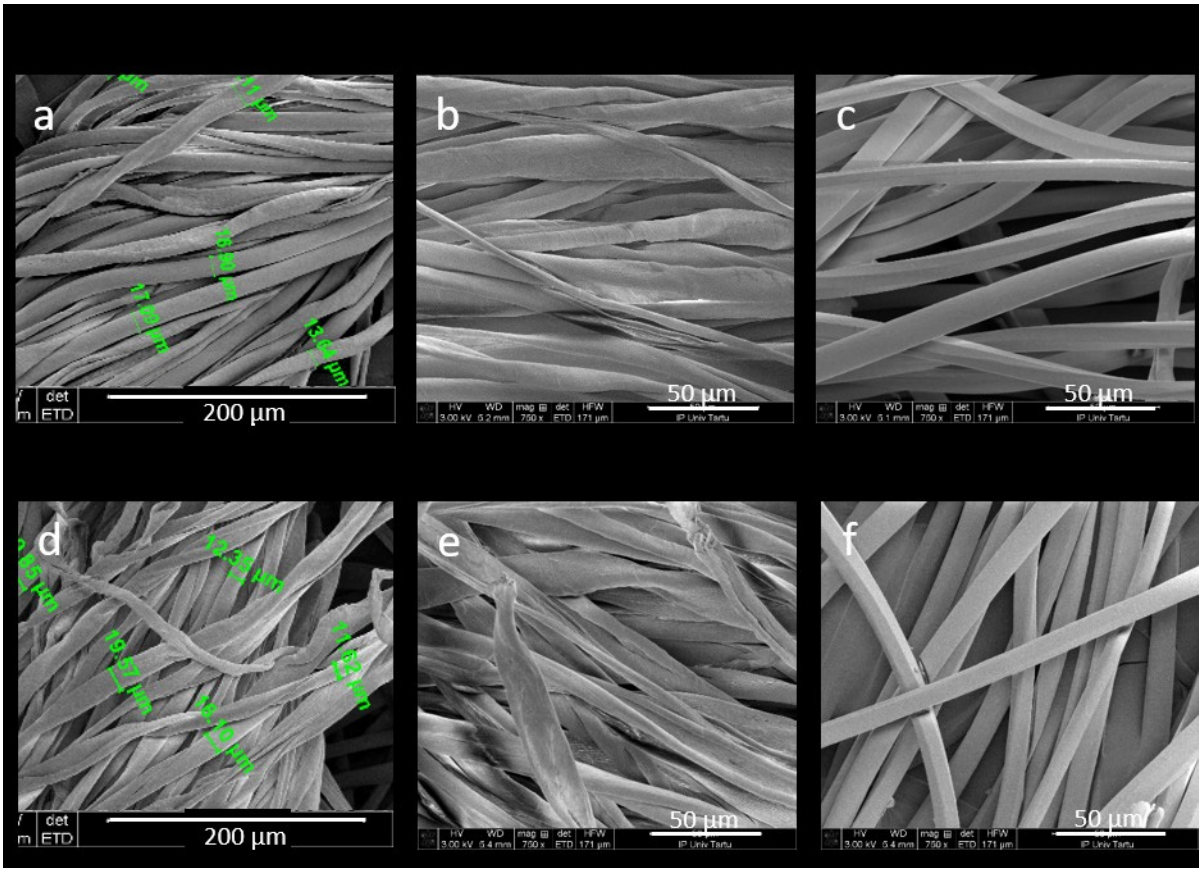

Figure 3. SEM images of the test sock (**a**–**c**) and control sock (**d**–**f**).

2.4. Assessment of Baseline Characteristics

To assess the baseline characteristics of the participants, a questionnaire was used [25].

2.5. Assessment of Foot Pain and Stiffness Intensity

Pain and stiffness in the ankle joint, as well as the metatarsophalangeal and toe joints, were measured using the Numeric Rating Scale (NRS) [26]. The participants were asked to circle the number that best described the pain he/she had felt due to rheumatoid or psoriatic arthritis in the ankle joint or metatarsophalangeal and toe joints over the past 24 h on a scale of 0–10, where 0 indicated no symptoms and 10 represented the greatest pain the participant could imagine. Similarly, severity of stiffness was reported. The right and left body side were assessed separately. Participants completed the NRS at the beginning of the study, as well as at 1, 6, and 12 weeks.

2.6. Assessment of Physical Function

Functional ability in daily life was assessed using the Estonian version of the Health Assessment Questionnaire—Disability Index (HAQ-DI) [27]. The questionnaire provides information on the patient's functional ability in eight different areas: rising, dressing and grooming, hygiene, eating, walking, reach, grip, and activities of independent living. Scoring for each subsection ranges from zero (no difficulty) to three (unable to perform), and a lower score indicates better functional ability. The HAQ-DI was completed by the participants at the beginning of the study, and then again at 1, 6, and 12 weeks.

2.7. Assessment of Health-Related Quality of Life

The Estonian version of the RAND 36-Item Health Survey (version 1.0) (RAND-36) was used to assess health-related quality of life [28]. The questionnaire consists of nine subscales, which are physical functioning, social functioning, role limitations due to physical problems, role limitations due to emotional problems, emotional well-being, energy/fatigue, bodily pain, general perception of health, and change in health over the last year. The subscale scores range from 0 to 100, with a higher score indicating better health-related quality of life. Participants completed the questionnaire at the beginning of the study, as well as at 1, 6, and 12 weeks.

2.8. Intervention

The study lasted for three months, during which it was necessary for participants to wear the socks (Incrediwear Holdings Inc., Chico, CA, USA) for at least eight hours a day (Figure 4). The socks were visually identical, except that the experimental group socks were marked with the letter A, and the control group socks were marked with the letter B.

Figure 4. Socks used in the study—Incrediwear.

Participants received written care instructions from the manufacturer, which were included with the patient information sheet and informed consent form. The instructions stated that the socks could be washed by hand or in a washing machine at temperatures up to 40 °C. Participants were advised not to bleach, iron, or dry-clean the socks, and to avoid drying them in a tumble dryer, on a radiator, or near other high heat sources.

2.9. Statistical Analysis

The data were analyzed using the SPSS software program (version 20; SPSS, Inc., Chicago, IL, USA). The Shapiro–Wilk test was used to determine whether the distribution of the studied variables followed a normal distribution. Since the distribution of most of the variables was not similar to a normal distribution, the Wilcoxon signed-rank test was used for comparisons of within-group values, and the Mann–Whitney U test was used for comparisons between group values. To examine changes, the baseline value was subtracted from the corresponding value at week 12. In the assessment of pain and stiffness of the ankle joint and metatarsophalangeal and toe joints, the data from the right and left body side were each pooled. Associations between categorical variables were assessed using Cramér's V. The effect size analysis of the Mann–Whitney U was calculated using the r equations as follows: $r = Z/\sqrt{n}$ [29]. Cohen's d was utilized to gauge effect sizes [30]. A significance level of $p < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of Participants

Table 2 presents the demographic and health-related data of the studied groups. The groups studied were similar with regard to most characteristics, except for the onset of disease symptoms and the time when RA or PA was diagnosed. The experimental group had a significantly shorter duration of disease symptoms ($p = 0.046$) and a shorter time since diagnosis of rheumatoid or psoriatic arthritis ($p = 0.012$) compared to the control group, despite random allocation.

Table 2. General characteristics of the study participants.

Variable	Experimental Group ($n = 23$)	Control Group ($n = 18$)
Age (years)	60 (38)	66 (11)
BMI (kg/m^2)	26.6 (5.5)	26 (7)
Females (%)	82.6	83.3
Employed (%)	56.5	44.4
Smoking (%)		
Now	17.4	21.7
Former smoker	11.1	33.3
Diagnosis		
RA (%)	87	88.9
PA (%)	13	11.1
RA or PA was diagnosed (years ago)	10 (16) *	20 (20)
Symptom onset (years ago)	10 (14) *	20.5 (18)
Prescription medications for RA or PA (%)	60.9	83.3

Note: The results are presented as median values (interquartile range) and percentages (%). * $p < 0.05$ between experimental and control groups. BMI—body mass index; RA—rheumatoid arthritis; PA—psoriatic arthritis.

There were no statistically significant differences between the experimental and control groups in the use of corticosteroids, conventional synthetic disease-modifying antirheumatic drugs, biologic disease-modifying antirheumatic drugs, or analgesics, including non-steroidal anti-inflammatory drugs. Cyclophosphamide was not used in either group. An overview of participant medication use is provided in Table S1 (Supplementary Materials).

3.2. Pain and Stiffness Intensity in the Ankle, Metatarsophalangeal and Toe Joints

Ankle pain scores were lower in the experimental group at week 1 ($p = 0.031$), week 6 ($p = 0.017$), and week 12 ($p = 0.002$) compared to the baseline values. In the experimental group, MTP and toe joint pain scores were lower at week 12 ($p = 0.008$) compared to the baseline value.

In the experimental group, ankle stiffness scores were lower at week 1 ($p = 0.012$), week 6 ($p = 0.007$), and week 12 ($p = 0.017$) compared to the baseline values. In the control group, ankle stiffness scores were lower at week 1 ($p = 0.037$) and MTP and toe joint stiffness scores were lower at week 6 ($p = 0.028$) compared to the baseline values.

MTP and toe joint pain scores were lower in the experimental group than in the control group at the start of the study ($p = 0.042$), at week 6 ($p = 0.017$), and at week 12 ($p = 0.001$, ES = 0.36). Additionally, ankle stiffness scores at week 12 ($p = 0.017$, ES = 0.26) and MTP and toe joint stiffness scores at the beginning of the study ($p < 0.001$), week 1 ($p = 0.014$), and week 12 ($p = 0.005$, ES = 0.31) were lower in the experimental group compared to the control group.

The changes in the intensity of ankle, MTP, and toe joint pain and stiffness during the 12-week study period did not differ between the groups (Table 3).

Table 3. Median (IQR) pain and stiffness intensity in the ankle, MTP, and toe joints at baseline, week 1, and week 12, with change scores and effect sizes in experimental and control groups.

	Group	Baseline [Median (IQR)]	Week 1 [Median (IQR)]	Week 12 [Median (IQR)]	Change [Median (IQR)]	Effect Size of Change
Pain intensity						
Ankle joint	EG ($n = 46$)	4 (4.3)	2 (3) #	2 (2.3) ¥	−1 (3)	0.21
	CG ($n = 36$)	3 (4)	2.5 (4)	3.5 (5)	0 (3.5)	
MTP and toe joints	EG ($n = 46$)	2 (5) *	2 (3)	1.5 (3) ¥	0 (2.5)	0.15
	CG ($n = 36$)	4 (4)	3 (4)	5 (5.8)	0 (5.5)	
Stiffness intensity						
Ankle joint	EG ($n = 46$)	3 (3)	2 (3) #	2 (3) ¥ *	0 (2.3)	0.18
	CG ($n = 36$)	4 (3)	3 (5) #	4 (5.8)	0 (3)	
MTP and toe joints	EG ($n = 46$)	2.5 (4) *	2.5 (4) *	2 (4) *	0 (3)	0.05
	CG ($n = 36$)	4.5 (3.5)	3.5 (4)	4 (6)	0 (4.8)	

Note: # $p < 0.05$ week 1 vs. baseline; ¥ $p < 0.05$ week 12 vs. baseline; * $p < 0.05$ between experimental and control groups. IQR—interquartile range; MTP—metatarsophalangeal joints; EG—experimental group; CG—control group.

3.3. Physical Function

In the control group, the HAQ-DI total score was lower at week 6 ($p = 0.011$) and week 12 ($p = 0.018$) compared to the baseline values. The control group also had a lower HAQ-DI reaching score at week 1 and a lower HAQ-DI hygiene score at week 12 ($p = 0.025$ and $p = 0.034$, respectively) compared to the baseline values.

In the experimental group, the HAQ-DI reaching score was lower at baseline ($p = 0.009$) and at week 12 ($p = 0.035$, ES = 0.33) compared to the control group. Additionally, the HAQ-DI activity score was lower at week 12 compared to the control group ($p = 0.028$, ES = 0.34).

The changes in the HAQ-DI total score and subscores during the 12-week study period did not differ between the groups (Table 4).

Table 4. Median (IQR) HAQ-DI subscales and total score at baseline, week 1, and week 12, with change scores and effect sizes in experimental and control groups.

	Group	Baseline [Median (IQR)]	Week 1 [Median (IQR)]	Week 12 [Median (IQR)]	Change [Median (IQR)]	Effect Size of Change
Dressing and grooming	EG ($n = 23$)	2 (2)	2 (2)	2 (2)	0 (0)	0.06
	CG ($n = 18$)	2 (1.3)	2 (1.3)	2 (1.3)	0 (0)	
Arising	EG ($n = 23$)	2 (1)	2 (2)	2 (2)	0 (0)	0.03
	CG ($n = 18$)	2 (1.3)	2 (1.3)	2 (1.3)	0 (1)	
Eating	EG ($n = 23$)	2 (1)	2 (1)	2 (1)	0 (0)	0.04
	CG ($n = 18$)	2 (1.3)	2 (1.3)	2 (1.3)	0 (0)	
Walking	EG ($n = 23$)	2 (2)	2 (2)	2 (2)	0 (0)	0.23
	CG ($n = 18$)	2 (1)	2 (1.3)	2 (1.3)	0 (0.3)	
Hygiene	EG ($n = 23$)	2 (1)	2 (2)	2 (2)	0 (0)	0.15
	CG ($n = 18$)	2 (1)	2 (1.5)	2 (0.5) ¥	0 (1)	

Table 4. *Cont.*

	Group	Baseline [Median (IQR)]	Week 1 [Median (IQR)]	Week 12 [Median (IQR)]	Change [Median (IQR)]	Effect Size of Change
Reaching	EG (*n* = 23)	2 (1) *	2 (1)	2 (1) *	0 (0)	0.16
	CG (*n* = 18)	2 (1)	2 (2) #	2 (1.3)	0 (0)	
Gripping	EG (*n* = 23)	2 (2)	2 (2)	1 (2)	0 (0)	0.09
	CG (*n* = 18)	2 (0)	2 (0.5)	2 (0.5)	0 (0)	
Usual activities	EG (*n* = 23)	2 (2)	2 (2)	1 (2) *	0 (0)	0.18
	CG (*n* = 18)	2 (0.3)	2 (2)	2 (1.3)	0 (0)	
Total score	EG (*n* = 23)	2 (1)	2 (1)	2 (2)	0 (0)	0.30
	CG (*n* = 18)	1.7 (1.6)	1.7 (2)	1.4 (1.9) ¥	0 (0.5)	

Note: # $p < 0.05$ week 1 vs. baseline; ¥ $p < 0.05$ week 12 vs. baseline; * $p < 0.05$ between experimental and control groups. HAQ-DI—Health Assessment Questionnaire–Disability Index; IQR—interquartile range; EG—experimental group; CG—control group.

3.4. Health Related Quality of Life

In the experimental group, the scores for physical ($p = 0.008$) and emotional ($p = 0.021$) limitations experienced in daily life were higher at week 12 compared to the baseline values. The pain score was higher in the experimental group at week 1 ($p = 0.029$), week 6 ($p = 0.014$), and week 12 ($p = 0.002$) compared to the baseline values.

In the control group, the general perception of health score was lower at week 12 ($p = 0.036$) compared to the baseline value. The score indicating role limitations due to emotional problems was lower in the control group at week 6 ($p = 0.048$), and the pain score was lower at week 1 ($p = 0.010$) and week 6 ($p = 0.010$) compared to the baseline values.

In the experimental group, the physical functioning score was higher at the beginning of the study ($p = 0.007$), week 1 ($p = 0.022$), and week 12 ($p = 0.013$, ES = 0.39) compared to the control group. The experimental group also showed a higher score for role limitations due to physical problems at week 1 ($p = 0.044$) and a higher score for social functioning at week 12 ($p = 0.024$, ES = 0.35) compared to the control group. Additionally, the bodily pain score was higher at the beginning of the study ($p = 0.003$), week 1 ($p = 0.003$), and week 12 ($p = 0.006$, ES = 0.43) in the experimental group compared to the control group. No other significant differences between groups were found for other values.

In the experimental group, the score indicating role limitations due to physical problems increased, while in the control group, it decreased during the 12-week study period. The difference in score changes between the groups was significant ($p = 0.029$, ES = 0.34). No significant between-group differences were observed for changes in other scores (Table 5).

Table 5. Median (IQR) RAND-36 subscales at baseline, week 1, and week 12, with change scores and effect sizes in experimental and control groups.

	Group	Baseline [Median (IQR)]	Week 1 [Median (IQR)]	Week 12 [Median (IQR)]	Change [Median (IQR)]	Effect Size of Change
General perception of health	EG (*n* = 23)	40 (35)	40 (25)	45 (30)	0 (20)	0.21
	CG (*n* = 18)	35 (28.8)	30 (28.8)	25 (28.8) ¥	−2.5 (12.5)	
Physical functioning	EG (*n* = 23)	55 (45) *	60 (40) *	50 (50) *	0 (10)	0.09
	CG (*n* = 18)	22.5 (50)	25 (56.3)	25 (26.3)	0 (22.5)	
Role limitations due to physical problems	EG (*n* = 23)	25 (75)	25 (50) *	50 (75) ¥	−25 (50) *	0.34
	CG (*n* = 18)	25 (50)	0 (25)	12.5 (62.5)	0 (31.3)	
Role limitations due to emotional problems	EG (*n* = 23)	0 (66.7)	33.3 (100)	100 (100) ¥	0 (66.7)	0.28
	CG (*n* = 18)	16.7 (100)	33.3 (100)	33.3 (100)	0 (41.7)	

Table 5. *Cont.*

	Group	Baseline [Median (IQR)]	Week 1 [Median (IQR)]	Week 12 [Median (IQR)]	Change [Median (IQR)]	Effect Size of Change
Social functioning	EG (n = 23)	62.5 (37.5)	62.5 (25)	50 (37.5) *	0 (25)	0.03
	CG (n = 18)	43.8 (65.6)	56.3 (78.1)	31.3 (61.3)	0 (62.5)	
Bodily pain	EG (n = 23)	45 (12.5) *	45 (22.5) * #	45 (22.5) * ¥	12.5 (22.5)	0.02
	CG (n = 18)	22.5 (37.5)	22.5 (22.5) #	27.5 (25.6)	11.3 (25)	
Energy/fatigue	EG (n = 23)	45 (15)	50 (15)	45 (35)	−5 (20)	0.04
	CG (n = 18)	30 (36.3)	30 (35)	35 (36.3)	−2.5 (23.8)	
Emotional well-being	EG (n = 23)	68 (24)	68 (16)	68 (28)	0 (20)	0.004
	CG (n = 18)	68 (17)	76 (17)	68 (30)	−4 (22)	
Perceived change in health over the last year	EG (n = 23)	50 (25)	50 (25)	50 (25)	0 (25)	0.13
	CG (n = 18)	50 (56.3)	50 (50)	50 (25)	0 (12.5)	

Note: # $p < 0.05$ week 1 vs. baseline; ¥ $p < 0.05$ week 12 vs. baseline; * $p < 0.05$ between experimental and control groups. RAND-36—RAND 36-Item Health Survey; IQR—interquartile range; EG—experimental group; CG—control group.

4. Discussion

The current study aimed to investigate the effect of Incrediwear functional textile socks, embedded with significantly higher concentrations of Zr, Ge, K, Ti, Zn, Mg, Cl, S, and P, compared to a control sock, on ankle and foot joint pain and stiffness, physical function, and health-related quality of life in patients with RA and PA.

The first main finding was that wearing the functional textile socks was only minimally effective in reducing pain and/or stiffness in the ankle, MTP, and toe joints, as measured by the NRS. Pain scores slightly improved in the experimental group by week 12, but no statistically significant between-group differences were found. Second, the subscores for "usual activities" and "reaching" within the HAQ-DI were improved in the functional sock group at the end of the study. However, despite these gains, wearing the functional textile socks was not associated with an overall significant increase in physical function. Third, improvements were observed in health-related quality of life as assessed by the RAND-36. Participants in the experimental group reported reduced role limitations due to physical problems, better physical functioning, improved social functioning, and lower bodily pain scores at week 12 compared to the control group.

Participant characteristics and adherence may have influenced these outcomes. There were no significant baseline differences between the experimental and control groups in age, sex, BMI, or medication use. However, a statistically significant difference was observed in disease duration and time since diagnosis, with the experimental group exhibiting shorter durations. These variables are potential confounders, as longer disease duration can influence pain perception, joint stiffness, and functional limitations. Although baseline pain, stiffness, and function scores were similar between the groups—partially mitigating concerns—this imbalance limits the internal validity of between-group comparisons. The differences likely arose due to the relatively small sample size despite random allocation. Future studies should consider stratified randomization or statistical adjustment for disease duration to address this limitation. Additionally, ten participants discontinued participation due to lower limb pain. However, dropout rates were similar across both groups, suggesting that the functional textile socks were not associated with greater adverse effects than the control socks.

To date, only a few studies have explored the effects of Incrediwear technology, which incorporates carbonized charcoal and Ge into fabric [12,13,31,32]. An in vitro study demonstrated that Incrediwear functional fabric embedded with carbonized charcoal and Ge can enhance human adipose-derived stem cell chondrogenic differentiation and maturity, potentially promoting cartilage regeneration [32]. Two clinical studies reported pain reduction and functional improvement when patients with osteoarthritis wore knee braces containing carbonized charcoal and Ge [12,13]. Justice and Jacob [31] compared Incrediwear sleeves with standard compression stockings after knee arthroplasty and found better knee flexion in the Incrediwear group, although differences in pain and range-of-motion changes were not statistically significant.

Despite the low Ge concentration in the socks, its role remains of interest. It is unclear whether a higher Ge dose would lead to more pronounced effects, as no dose-comparison studies have yet been conducted. Moreover, Ge is costly, limiting its large-scale use in consumer textiles. Thermal safety concerns associated with semi-metallic compounds in clothing—such as potential overheating—further constrain the use of high Ge concentrations [33].

Nevertheless, textiles incorporating Ge—particularly in combination with carbon—may hold potential for bioactivity, as suggested by preliminary studies using Ge- and carbon-infused knee sleeves in osteoarthritis patients [12,13]. Fabrics containing these materials have demonstrated increased blood circulation via far-infrared radiation when warmed by body heat [32]. Enhanced capillary flow may support oxygen and nutrient delivery to inflamed tissues, accelerate metabolic waste removal [34,35], and reduce inflammation [34].

Textiles containing bioceramic materials, which share some characteristics with Ge-based fabrics, have also shown potential anti-inflammatory effects by increasing nitric oxide production and decreasing cyclooxygenase-2 expression in cell studies. These markers are relevant to vasodilation and inflammatory modulation in diseases like RA [36].

While earlier studies focused primarily on Ge as the functional element in performance textiles, the present study applied XRF technology to comprehensively characterize the elemental composition of the socks. This analysis revealed that the experimental socks, in addition to containing Ge, also had significantly higher concentrations of several other elements—including Zr, Ti, Zn, Mg, Cl, S, and P— compared to the control socks, with Zr completely absent in the latter. This chemical profiling enhances the interpretability of our findings and underscores the importance of including detailed compositional analysis in future textile intervention research, as well as a more thorough examination of the sock-making process and the precursors used.

Since the socks' fiber morphology was highly similar between the two groups, suggesting comparable textile structure and physical characteristics, the observed effects likely stemmed from differences in elemental content rather than textile architecture.

Some of these additional elements may contribute to properties such as antimicrobial activity (Zr, Ti, Zn, Cl, S) [37–40], ultraviolet protection (Zr, Ti, Zn) [41–43], or flame retardancy (P, S, Ti, Zr, Mg) [44,45]; potassium, commonly used in textile processing for pH regulation and impurity removal, may have been introduced during manufacturing [46,47]. Although the presence of additional elements—such as Zr, Ti, Zn, Mg, and others—raises the possibility that they may have contributed to the observed outcomes through secondary mechanisms, their inclusion appears to be primarily a byproduct of the manufacturing process. Given the existing literature on Ge's bioactive properties and the manufacturer's claim that Ge is the defining feature of the functional textile, it is reasonable to speculate that Ge played a central role. However, due to the lack of experimental isolation of individual elements in this study, a definitive attribution is not possible.

5. Strengths and Limitations

A major strength of this study is its randomized, double-blind, placebo-controlled design. Participants were randomly assigned to groups, and both participants and assessors were blinded to group allocation, reducing the risk of bias. Such a design represents the gold standard for testing the efficacy of interventions [48].

This study also advanced the methodology compared to prior textile studies by including a control group, utilizing blinding, and conducting independent chemical analysis of the textile composition using X-ray fluorescence spectrometry (XRF) and scanning electron microscopy (SEM)—an aspect lacking in previous studies, which typically relied on manufacturer-provided data [12,13,31].

However, this study has several limitations. First, the relatively small sample size limits statistical power and may have contributed to baseline imbalances despite randomization. Notably, participants in the experimental group had a shorter disease duration, which could act as a confounder, although baseline symptom scores were similar. Second, while participants were instructed to wear the socks for at least eight hours daily, exact wear time was not tracked, preventing dose–response analysis. Third, although blinding procedures were implemented and socks were visually and structurally matched, we did not formally assess the success of blinding, introducing potential for expectation bias, particularly in subjective outcomes. Fourth, data on non-pharmacological co-interventions (e.g., physical therapy, infrared therapy) were not systematically collected, which may have influenced pain and function outcomes. Finally, while textile composition was analyzed using XRF and SEM, future studies could employ more sensitive techniques [e.g., inductively coupled plasma mass spectrometry (ICP-MS)] to further investigate element–tissue interactions and explore properties such as infrared emissivity.

6. Conclusions and Future Directions

Wearing functional textile socks resulted in some statistically significant improvements in foot and ankle pain and stiffness, as well as in aspects of physical function and health-related quality of life in individuals with rheumatoid and psoriatic arthritis. However, these effects were small, and their clinical relevance remains uncertain. Limitations such as small sample size, unmeasured wear time, baseline imbalance in disease duration, and lack of blinding validation may have introduced bias and thus may limit generalizability.

Future research should use larger, stratified samples, incorporate adherence tracking, and formally assess blinding effectiveness, especially when subjective outcomes are involved. Investigating the dose–response effects of individual elements—particularly germanium—and assessing physical properties such as infrared emissivity could help clarify underlying mechanisms. Advanced analytic methods like ICP-MS may also enhance understanding of material–tissue interactions and inform the design of future therapeutic textiles.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/textiles5030030/s1, Table S1: Medications used by participants in the experimental and control groups, including prescription and over-the-counter analgesics. Values indicate the percentage of participants who reported using each medication category at the time of data collection.

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Institutional Review Board Statement: Ethical approval was obtained from the Research Ethics Committee of the University of Tartu, Estonia (references 345/T-23 and 362/M-2, dated 14 March 2021 and 18 April 2022, respectively). This study was conducted in agreement with the Declaration of Helsinki.

Informed Consent Statement: Written informed consent was provided by all participants.

Data Availability Statement: The datasets used in this study are available from the corresponding author upon reasonable request due to privacy and ethical reasons.

Conflicts of Interest: Incrediwear Holdings Inc. (USA) provided the socks for this work. The company had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript, and did not influence the outcomes or interpretation of the results. Kristiine Hõrrak is employed by Hortusmedicus, a company involved in the sale of the socks evaluated in current study. This affiliation may represent a potential conflict of interest related to the work.

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