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Do ginger footbaths improve symptoms of insomnia more than footbaths with warm water only? – A randomized controlled study☆

Silja Kuderer [a], Katrin Vagedes [a], Henrik Szöke [b], Matthias Kohl [c], Stefanie Joos [d], Peter W. Gündling [e], Jan Vagedes [a,f,g,*]

[a] Research Department, ARCIM Institute (Academic Research in Complementary and Integrative Medicine), Im Haberschlai 7, 70794 Filderstadt, Germany
[b] Department of Integrative Medicine, University of Pécs, Vörösmarty utca 3, 7623 Pécs, Hungary
[c] Institute of Precision Medicine, University Furtwangen, Jakob-Kienzle-Straße 17, 78054 VS-Schwenningen, Germany
[d] Institute for General Practice and Interprofessional Care, University Hospital Tübingen, Osianderstraße 5, 72076 Tübingen, Germany
[e] Hochschule Fresenius, University of Applied Sciences, Limburger Str. 2, 65510 Idstein, Germany
[f] Department of Neonatology, University Hospital Tübingen, Calwerstraße 7, 72076 Tübingen, Germany
[g] Department of Pediatrics, Filderklinik, Im Haberschlai 7, 70794 Filderstadt, Germany

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ABSTRACT

Objectives: To compare the effects between warm water (WW) and ginger footbaths (WW+ginger) on sleep quality and warmth regulation in adults with self-reported insomnia symptoms.
Methods: A prospective randomized-controlled study in which 28 participants (mean age 50.9 years, 64.3% women, insomnia symptom duration 11.4 years) were randomized to receive WW ($n = 13$) or WW+ginger ($n = 15$) daily for 2 weeks. Treatment involved nightly footbaths (12 liters of 38–42 °C warm tap water, maximum duration 20 min) with and without topical ginger (80 g of powdered ginger rhizomes).
Main outcome measures: The primary outcome measure was self-reported sleep quality (global score from Pittsburgh Sleep Quality Index, PSQI) at 2 weeks. Secondary outcomes included measures of insomnia severity (Insomnia Severity Index, ISI) and warmth regulation (Herdecke Warmth Perception Questionnaire, HWPQ and 24-hour distal-proximal skin temperature gradient, DPG).
Results: WW+ginger had no greater effect on PSQI (mean *between*-difference 0.0 [95% CI −3.0 to 2.9], Cohen's d=0.0) or ISI (−0.2 [−3.9 to 3.4], 0.0) than WW. Nor were there any significant differences in HWPQ perceived warmth (0.1 $\geq d \geq$0.5) or DPG (0.1 $\geq d \geq$0.4) between WW and WW+ginger. Both groups improved over time in PSQI (WW+ginger: d=0.7, WW: d=1.3) and ISI (WW+ginger: d=0.8, WW: d=1.0). Perceived warmth of the feet increased only in WW+ginger over time (d=0.6, WW: d=0.0).
Conclusions: This dose of ginger (6.67 g/liter) did not have greater effects on sleep quality, insomnia severity or warmth regulation than WW. Considering effect sizes, costs and risks, the use of WW would be recommended over WW+ginger in this patient population.

1. Introduction

Abnormalities in the circadian body temperature rhythm are hypothesized to be associated with the development of insomnia symptoms.[1] Because of its synchronization with the sleep-wake rhythm, a healthy body temperature pattern can be important for both sleep initiation and sleep maintenance.[1–3] Complex networks of circadian clocks, including the suprachiasmatic nuclei (SCN) of the hypothalamus and peripheral clocks (in peripheral tissues and organ systems), generate circadian rhythmicity.[4] The SCN-driven rhythm of core body temperature[4] is nearly sinusoidal with a temperature peak around 5PM and a nadir at 5AM.[1,5] The evening decrease in core body temperature is primarily caused by heat loss from the core to the periphery (extremities).[2,6–9] Increased distal vasodilation (associated with increased skin temperature in the extremities) is the basis of this convective heat transfer and is initiated by the release of melatonin[6,10] and behaviors such as postural change to a supine position and the use of warmth-enhancing bedding.[11,12]

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* Correspondence to: ARCIM Institute, Im Haberschlai 7, 70794 Filderstadt, Germany.
E-mail address: j.vagedes@arcim-institute.de (J. Vagedes).

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The distal-proximal skin temperature gradient (DPG), calculated by subtracting the proximal skin temperature from the distal skin temperature, reflects the degree of vasodilation in the skin of the hands and feet, and serves as an indirect measure of distal heat loss.[11] Higher DPG values (≥0 °C) at bedtime (before lights out) are associated with an increased sleep propensity,[11,13,14] as reflected by faster sleep onset,[15] fewer nighttime awakenings, and higher sleep efficiency.[16] Some sleep disorders may result from an inability to vasodilate peripherally,[11,13] leading to increased core temperature at night and reduced propensity for sleep.[1,17] Thus, cold feet in the evening could indicate insufficient distal vasodilation and contribute to poor sleep.[2,18]

Exogenous skin warming can positively influence sleep quality, latency, and efficiency.[1,6,19–22] Footbaths are a cost-effective intervention [23] that can be easily and safely applied at home.[20,23,24] The feet are a body region with a high density of thermoreceptors and many capillaries.[25,26] Hence, warm footbaths can rapidly influence peripheral vasodilation[11,19–22] and support the body's physiological sleep preparation, inducing an increase in DPG.[13,26] Previous research has focused mainly on footbaths with warm water only (WW).[2,19–21,23,27,28] The addition of ginger powder (Zingiber officinale) may further enhance the effect of WW on sleep.[29,30]

The active ingredients of ginger, gingerols and shogaols, can penetrate the skin and activate transient receptor potential (TRP) channels (mainly TRP vanilloid receptor 1, TRPV1).[31–33] TRP channels are expressed on peripheral sensory neurons and play a key role in early thermosensation transduction.[34] The nerve impulse generated by channel activation is transmitted to the central nervous system, where it is integrated and interpreted as a sensory response.[34] Moreover, TRP channel activation triggers the release of vasoactive neuropeptides including substance P and calcitonin gene-related peptide.[35] Interestingly, reduced peripheral blood flow may chronically affect sensations of warmth.[36] Therefore, nightly footbaths with added ginger powder (WW+ginger) may improve reduced peripheral blood flow, warmth perception and poor sleep by activating TRP channels. The associated increase in skin blood flow (with higher DPG values) and warmth perception may contribute to better sleep.

We hypothesized that among adults with self-reported insomnia symptoms, WW+ginger would generate greater improvement than WW on (1) self-reported sleep quality and insomnia severity; (2) perceived warmth using the Herdecke Warmth Perception Questionnaire (HWPQ); and (3) DPG.

2. Material and methods

2.1. Study design

The study was a prospective, open-label, parallel group, randomized, vehicle-controlled trial. The trial was conducted at an anthroposophical hospital in Germany with a total of 28 adult participants who were allocated to two interventions using permuted block randomization: the active intervention, WW+ginger ($n = 15$), and the control intervention, WW ($n = 13$). The study was approved by the Ethics Committee of the Medical Association of Baden-Württemberg in Stuttgart, Germany (F-2019-112), registered at ClinicalTrials.gov (NCT04210895), and complied with the CONSORT (Consolidated Standards of Reporting Trials) guidelines.[37] All participants provided written informed consent before enrollment. The study was part of a larger initiative that aimed to examine the effects of footbaths with ginger powder on health-related quality of life and heart rate variability in adults with self-reported insomnia symptoms (not yet published).

2.2. Study population

Participants were recruited through notices in local stores, pharmacies, and medical practices, as well as advertisements in the daily press and social media from December 2019 to April 2020. Eligibility criteria included age between 18 and 70 years and self-reported insomnia symptoms (poor sleep quality, difficulty initiating or maintaining sleep, waking up too early). Potential participants were excluded if they reported periodic limb movement disorder, restless leg syndrome, sleep apnea, narcolepsy or acute mental illness, and if they were currently prescribed benzodiazepines, H1-antihistamines, neuroleptics, tricyclic and tetracyclic antidepressants or chloral hydrate. Further exclusion criteria were night shift work, pregnancy, skin conditions of the lower legs or feet, varicose veins (Marshall's degree 3 and 4), chronic venous insufficiency, hypersensitivity to ginger products, participation in other studies, and insufficient fluency of the German language. Participants who met inclusion criteria were asked to provide demographic and baseline characteristics, including age, sex, height and weight (used to determine body mass index, BMI), relationship status, duration of insomnia symptoms, and any chronic disease diagnosis.

2.3. Procedure

Interested individuals were pre-screened by telephone based on the study criteria. Then potential participants received a letter with study information materials. At the first appointment, individuals were informed in detail about the study. If they decided to participate and provided written informed consent, they were screened for eligibility. Eligible participants were randomly assigned to one of the two interventions (active intervention, WW+ginger or control intervention, WW) using permuted block randomization. The study outcome measures were assessed at the first appointment (Baseline) and following the two-week footbath intervention (Post). Participants received the following study materials: a plastic footbath tub (42×30×36 cm), a digital thermometer (Mivolis SC 41 flex, dm-drogerie markt GmbH + Co. KG, Karlsruhe, Germany) and, for those assigned to WW+ginger, 1.12 kg of powdered ginger rhizomes (rhizoma zingiberis mundat. powder, manufactured by Caesar & Loretz GmbH, Hilden, Germany) packed in 80-gram sachets. The ginger powder was produced according to Good Manufacturing Practice (GMP) in compliance with the German Drug Law (AMG) and the German Good Manufacturing Regulation (Arzneimittel- und Wirkstoffherstellungsverordnung, AMWHV). The two-week intervention period began the day after Baseline data collection. Due to the COVID-19 pandemic, the Post measurements of five participants could not be performed at the hospital, but rather the participants self-administered the measurements at home with the structured guidance of written instructions and/or instructional videos (documents and materials required for these Post outcomes were sent by mail).

2.4. Intervention

The intervention consisted of daily footbaths over a two-week period, prepared and administered by the participants themselves. At the first Baseline appointment, the participants learned from the researcher how to perform the footbaths correctly. They were instructed to prepare and administer the footbaths 1–3 h before their usual bedtime, in a quiet and comfortable environment, with 12 liters of warm water heated to 40 ± 2 °C, in the plastic tub provided (water depth: 15 cm). A mark on the tub at 15 cm facilitated the preparation. Water temperature was measured with a digital thermometer. For WW+ginger, 80 g (dose: 6.67 g/liter) of pre-measured ginger powder (one sachet) was added and stirred in.

In a seated position, participants then placed their feet into the plastic tub for a maximum of 20 min. They were instructed to discontinue the footbaths in the event of discomfort or profuse perspiring. After the footbath, the feet were dried with a towel and participants were encouraged to rest and avoid physically stimulating activities before bedtime. For each of the 14 days of footbaths, participants documented the date, time of day, water temperature (at the beginning and at the end of footbath), duration, personal observations and experiences (including

describing any symptoms of discomfort), and bedtime in the evening. The research assistant was available by phone or email at any time during the intervention period to answer questions. At the Post appointment, participants were also asked to describe any adverse events.

2.5. Outcome measures

2.5.1. Pittsburgh Sleep Quality Index (PSQI)

The PSQI is a validated, patient-reported, 19-item questionnaire that can be used to effectively measure sleep quality and disturbances over the past month (Cronbach's $\alpha = 0.83$).[38,39] The items constitute seven component scores including subjective sleep quality (1 item), sleep latency (2 items), sleep duration (1 item), habitual sleep efficiency (3 items), sleep disturbances (9 items), use of sleeping medications (1 item), and daytime dysfunction (2 items), each ranging from 0 to 3 with higher scores indicating poorer sleep. The PSQI global score is calculated as the sum of all component scores and ranges from 0 to 21, with a cut-off value of 5 (or greater) indicating poor sleep quality.[40] We modified the PSQI by reducing the recall period to the last two weeks (instead of one month).

2.5.2. Insomnia Severity Index (ISI)

The ISI is a validated, 7-item self-report questionnaire to measure the severity and impact of insomnia symptomatology over the past two weeks (Cronbach's $\alpha = 0.91$).[41] Items are rated on a 5-point scale (e.g., from 0 =no problem to 4 =very severe problem) and summed to produce a total score (ranging between 0 and 28) that is interpreted as follows: 0–7 =no insomnia, 8–14 =sub-threshold insomnia, 15–21 =moderate insomnia, and 22–28 =severe insomnia.[41]

2.5.3. Herdecke Warmth Perception Questionnaire (HWPQ)

The HWPQ (Herdecker Wärmeempfindungs-Fragebogen) is a self-report questionnaire to assess subjective warmth perception. The state version of the HWPQ measures the current self-perceived body warmth in 24 body parts as well as overall warmth (Cronbach's $\alpha = 0.93$).[42,43] Items are rated on a 5-point scale, ranging from 0 =cold to 4 =hot. Items from adjacent smaller areas were averaged to obtain scores for the outcome measures face, hands, and feet (4 face items: top of head, forehead, back of head, and cheeks; 2 hand items: hands and fingers; 2 foot items: feet and toes). Overall warmth is reported as a single item.

2.5.4. Distal-proximal skin temperature gradient (DPG)

We used MAXIM iButton™ DS1922L sensors (Maxim Integrated, San Jose, California, USA) to continuously measure the DPG at Baseline and Post at two-minute intervals over a 24-h period. The iButton is a non-invasive, safe and reliable instrument that can detect and record temperatures between 15 and 46 °C with an accuracy of 1 °C and a resolution of 0.125 °C.[13] We used two iButtons per measurement, which were attached to the skin with medical adhesive patches: the proximal skin temperature sensor was placed on the right side of the abdomen in the supply area of the femoral artery and the distal skin temperature sensor was placed on the dorsum of the right foot. DPG was calculated by subtracting the proximal value from the distal value.[14]

Additionally, participants recorded the times of going to bed, falling asleep, nocturnal active phases (involving getting out of bed), and waking up and getting out of bed the next morning. Data from the first 30 min after attaching the iButtons to the skin and nocturnal active phases were discarded to reduce potential bias due to skin adaptation in the first minutes of measurement and possibly abruptly changing ambient conditions during nocturnal active phases. The remaining data were consolidated into blocks as follows: Day (D1), sleep preparation (D2: 30 min before bedtime), sleep latency (S1: time between going to bed and falling asleep), sleep onset (S2: the first 30 min after falling asleep), and night (S3: 4.5 h of sleep after S2).

2.6. Primary and secondary outcome measures

All study outcome measures were collected at Baseline and Post. Our primary outcome measure was self-reported sleep quality, assessed with the global PSQI score, at Post. Secondary outcome measures included ISI total score, HWPQ warmth perception of face, hands, and feet, HWPQ overall warmth, and DPG during D1, D2, S1, S2, and S3 at Post.

2.7. Sample size

Since we could not identify any other published study that investigated the effect of footbaths with the addition of the thermogenic substance ginger on self-reported sleep quality, no data were available on the potential treatment effect. We estimated that a sample of 30 participants with an allocation ratio of 1:1 would be sufficient for the purpose of this initial investigation.

2.8. Randomization

Participants were stratified by HWPQ warmth perception of the feet (<3 cold feet vs. ≥ 3 warm feet) and randomly assigned to WW (control intervention) or WW+ginger (active intervention) using a permuted block randomization (block size varied between two and four). Participants were allocated at the first appointment according to the randomization list. Randomization was performed by the research assistant.

2.9. Statistical analysis

All analyses were performed using R and RStudio.[44,45] In accordance with the ICH E9 guideline,[46] data were analyzed with the intention-to-treat principle based on the Full Analysis Set. Missing values were replaced with single imputation using predictive mean matching.[47] We generated a total of 40 imputed datasets and averaged them to obtain single imputation values. A two-sided p-value < 0.05 was considered significant. Potential differences in baseline demographics were examined with Welch two sample t-tests and Fisher's exact tests.

The primary outcome measure, global PSQI score at Post, was analyzed using a linear mixed effects model.[48] A random intercept was included for each participant. Intervention (WW, WW+ginger) and time (Baseline, Post) were fitted as fixed effects. An interaction term between intervention and time was included to assess the intervention effect at each timepoint. The assumptions of normality, heteroscedasticity, and the presence of outliers were checked graphically. A likelihood ratio statistic and a calculation of the Akaike and Bayesian information criteria (AIC and BIC) were performed to compare a model without covariates with a model in which age, number and duration of footbaths, and initial water temperature were included as covariates. An analysis of variance was conducted with the final model and significant main effects were followed up by post hoc analyses.[49] A Bonferroni correction was applied to adjust for multiple testing within these analyses and Cohen's d effect sizes were calculated.[50]

A sensitivity analysis (sensitivity analysis A) was conducted to compare the results of the final linear mixed model (without covariates) with those of the model that was discarded in the process of model selection (model with covariates). Potential influential observations were detected with Cook's distance (with $\frac{4}{n}$ as a cut-off)[51] and the primary analysis was repeated after omitting these observations (sensitivity analysis B).

Secondary outcome measures were analyzed descriptively. Mean differences, 95% confidence intervals (CI) and Cohen's d effect sizes were calculated to examine the difference between both interventions at each timepoint (called *between*-analysis) and the change over time for each intervention (called *within*-analysis). Potential differences in the footbath interventions (number and duration of footbaths, initial water

temperature, extent of water cooling during the footbaths, and time between footbath and bedtime in minutes) between both interventions were analyzed with Welch's t-tests.

3. Results

3.1. Participants

A total of 85 adults were screened for eligibility. Of those, twenty did not meet inclusion criteria and 29 declined to participate. Due to the COVID-19 pandemic, we needed to terminate recruitment early. As a result, 7 potential participants were excluded prior to randomization. A total of 29 participants were initially enrolled and randomly assigned; thus, the actual sample size was one subject fewer than the planned number of participants (30). One participant (WW+ginger) withdrew immediately after randomization. According to the Full Analysis Set,[46] this participant was excluded from the analysis because she did not receive the allocated intervention and no data were collected post randomization. One participant (WW+ginger) dropped out for medical reasons, and another (WW+ginger) was lost to follow-up for personal reasons (available data were included in the analysis according to the intention-to-treat principle). The final sample consisted of 28 participants (WW: $n = 13$, WW+ginger: $n = 15$, Fig. 1).

The participants had a mean age of 50.9 ± 12.9 (mean ± standard deviation) years (range 27–69), a mean body mass index of 25.4 ± 3.9 kg/m^2, and 64.3% were female (Table 1). The mean insomnia duration was 11.4 ± 9.7 years (range 1 month-35 years, missing data $n = 7$). The mean global PSQI score at Baseline was 10.9 ± 2.5 (range 6–15) and the mean ISI total score was 16.7 ± 3.6 (range 11–25), indicating moderate insomnia severity. According to the ISI items' response of severe or very severe symptoms (corresponds to ratings of 3 and 4 on a scale from 0 =none to 4 =very severe), 12 participants (42.9%) reported symptoms of mixed sleep onset and maintenance insomnia, 10 participants (35.7%) reported symptoms of sleep maintenance insomnia, and 3 participants (10.7%) symptoms of sleep onset insomnia. Three participants (10.7%) rated none of the insomnia items as severe or very severe. One participant (3.6%, WW) was taking herbal medicine (valerian root dry extract, 450 mg/day), and 2 participants (7.1%, both WW+ginger) were taking other substances for sleep disorders (melatonin, 1 mg/day, and L-tryptophan, unknown dosage,

Table 1
Demographic and baseline characteristics of participants.

	WW ($n = 13$)	WW+ginger ($n = 15$)	p
Age, years	50.2 ± 11.6	51.5 ± 14.4	0.80
Sex, male/female	4/9	6/9	0.71
BMI, kg/m^2	25.2 ± 3.6	25.6 ± 4.3	0.78
Relationship status			0.40
Partnered	11 (84.6)	10 (66.7)	
Not partnered	2 (15.4)	5 (33.3)	
Chronic medical illnesses[a]	2 (15.4)	2 (13.3)	1.00
Insomnia duration, years[b]	13.5 ± 10.4	9.8 ± 9.4	0.41

Data are presented as mean ± SD or n (%). Welch two sample t-tests or Fisher's exact tests were performed to compare characteristics between the two groups. WW=footbath with warm water only, WW+ginger=footbath with ginger powder, BMI=body mass index.

[a] WW+ginger: Hearing loss ($n = 1$) and myelodysplastic syndrome ($n = 1$), WW: rheumatoid arthritis & hypothyroidism ($n = 1$) and bowel disease ($n = 1$). For relationship status, "partnered" means lives with partner or married, "not partnered" is single, separated, or divorced.

[b] Missing data $n = 7$ (WW: $n = 4$, WW+ginger: $n = 3$).

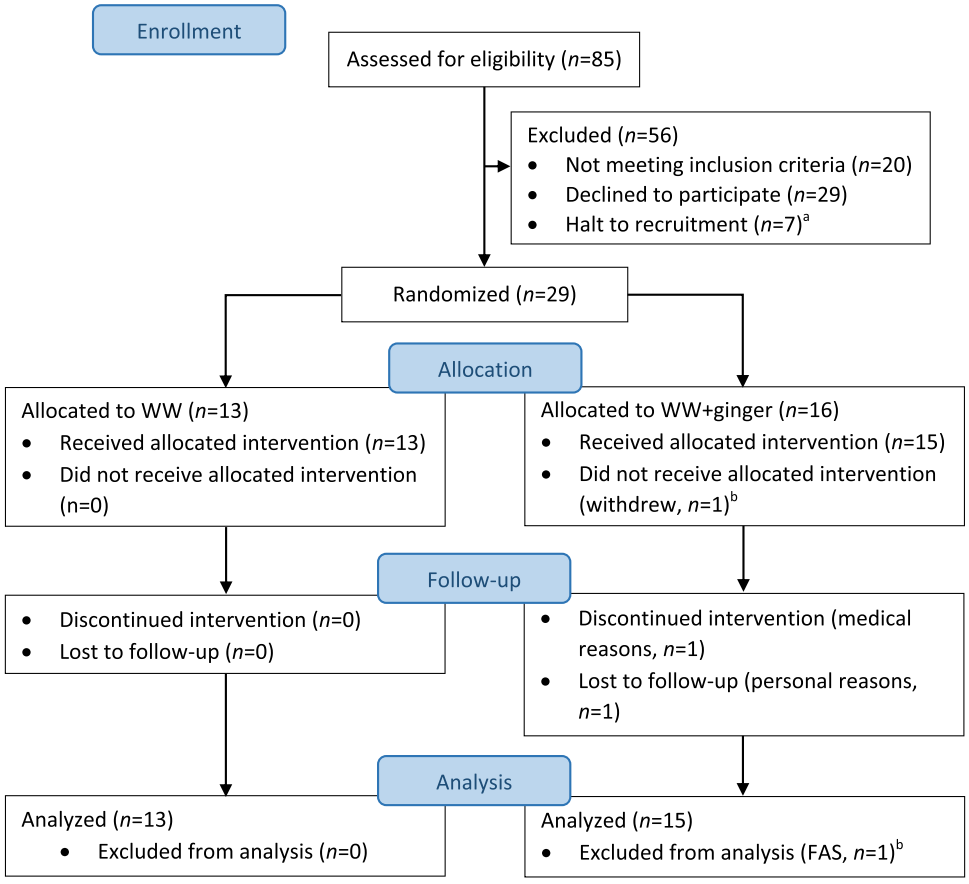

Fig. 1. Participant flow. WW=footbath with warm water only, WW+ginger=footbath with ginger powder. [a]Recruitment had to be terminated early due to the COVID-19 pandemic. [b]Excluded from analysis based on the Full Analysis Set (FAS) principle.

Table 2
Mean values (± standard deviations) and descriptive *between*-group differences for the primary and secondary outcome measures.

	Baseline			Post		
	WW	WW+ginger	Diff [CI]; ES	WW	WW+ginger	Diff [CI]; ES
Self-reported sleep quality						
PSQI global score	11.7 ± 2.6	10.1 ± 2.4	1.6 [− 0.4;3.5]; 0.6	7.7 ± 3.5	7.7 ± 4.2	0.0 [− 3.0;2.9]; 0.0
ISI total score	16.8 ± 3.5	16.6 ± 3.8	0.2 [− 2.7;3.0]; 0.0	12.6 ± 4.5	12.9 ± 5.0	-0.2 [− 3.9;3.4]; 0.0
Warmth perception (Herdecke Warmth Perception Questionnaire, HWPQ)						
Face	2.5 ± 0.5	2.5 ± 0.7	0.0 [− 0.4;0.5]; 0.0	2.4 ± 0.9	2.5 ± 0.7	-0.1 [− 0.8;0.5]; 0.2
Hands	2.6 ± 0.9	2.5 ± 0.9	0.0 [− 0.7;0.8]; 0.0	2.2 ± 1.0	2.3 ± 1.0	-0.1 [− 0.9;0.7]; 0.1
Feet	2.1 ± 1.0	1.9 ± 1.0	0.2 [− 0.6;1.0]; 0.2	2.1 ± 1.2	2.4 ± 0.8	-0.3 [− 1.1;0.5]; 0.3
Overall warmth	2.5 ± 0.8	2.7 ± 0.7	-0.2 [− 0.8;0.4]; 0.3	2.1 ± 1.0	2.5 ± 0.6	-0.4 [− 1.0;0.3]; 0.5
Distal-proximal skin temperature gradient, in °C						
D1	-2.4 ± 2.5	-2.1 ± 2.9	-0.2 [− 2.3;1.8]; 0.1	-2.8 ± 2.0	-2.7 ± 2.4	-0.1 [− 1.8;1.5]; 0.1
D2	-2.1 ± 3.3	-1.1 ± 2.4	-1.0 [− 3.3;1.4]; 0.3	-1.5 ± 1.3	-1.2 ± 1.7	-0.3 [− 1.4;0.9]; 0.2
S1	-2.3 ± 3.0	-0.9 ± 2.0	-1.4 [− 3.5;0.6]; 0.6	-1.7 ± 1.6	-1.0 ± 1.8	-0.6 [− 1.9;0.7]; 0.4
S2	-2.2 ± 3.0	-0.8 ± 1.8	-1.4 [− 3.4;0.5]; 0.6	-1.8 ± 1.7	-1.1 ± 1.7	-0.6 [− 2.0;0.7]; 0.4
S3	-0.9 ± 0.8	-0.7 ± 0.5	-0.3 [− 0.8;0.3]; 0.4	-1.0 ± 0.6	-0.9 ± 0.4	-0.1 [− 0.5;0.3]; 0.2

WW=footbath with warm water only (n = 13), WW+ginger=footbath with ginger powder (n = 15), Diff=mean difference, CI= 95% confidence intervals, ES=Cohen's d effect size, PSQI= Pittsburgh Sleep Quality Index, ISI= Insomnia Severity Index, D1 =day, D2 =sleep preparation, S1 =sleep latency, S2 =begin of sleep, S3 =night. PSQI global score ranges from 0 to 21 (≥5 indicates poor sleep quality). ISI total score ranges from 0 to 28 (0–7 =no, 8–14 =sub-threshold, 15–21 =moderate, and 22–28 =severe insomnia). HWPQ scores range from 0 =cold and 4 =hot.

irregular intake). Baseline measurements of study outcome measures were similar in both interventions (Table 2).

3.2. Intervention adherence

The mean time interval between Baseline and Post appointment was 15.3 ± 1.5 days. Accordingly, the mean intervention period (between Baseline and Post) was 14.4 ± 1.5 days (range 13–20), during which participants performed an average of 11.4 ± 2.0 (range 5–14) footbaths (total number of footbaths performed: WW: $n = 144$, WW+ginger: $n = 175$). No significant differences were observed between WW and WW+ginger, indicating similar intervention adherence (Table 3). However, we recorded deviations from the study protocol in both intervention groups in terms of time between footbath and bedtime (WW: 21 out of a total of 144 footbaths, 14.6%, WW+ginger: 49 out of a total of 175 footbaths, 28.0%), water temperature (WW: 7/144, 4.9%, WW+ginger: 21/175, 12.0%), and footbath duration (WW: 1/144, 0.7%, WW+ginger: 26/175, 14.9%).

3.3. Model selection

The likelihood ratio statistic [$X^2_{diff}(4) = 6.91, p = 0.14$] as well as the AIC (without covariates: 282.3, with covariates: 283.4) and BIC (without covariates: 294.5, with covariates: 303.7) indicated better data approximation by the model without covariates. The inspection of the data revealed no extreme outliers and the primary outcome measure did not differ significantly between both interventions at Baseline (Table 2). Thus, no covariates were entered into the analytic model for the primary analysis.

A total of 2.1% (22/1064) of PSQI, 2.0% (8/392) of ISI, and 1.8% (25/1400) of HWPQ data as well as 7.1% (4/56) of DPG measurements were missing and imputed with predictive mean matching.

3.4. Primary outcome measure

WW+ginger did not have a greater effect on the global PSQI score than WW. Neither the factor intervention [$F(1,26) = 0.46, p = 0.51$] nor the interaction [$F(1,26) = 2.52, p = 0.12$] between time and intervention reached significance.

However, a significant main effect of time [$F(1,26) = 40.40$, $p < 0.001$, Baseline: 10.9 ± 2.5, Post: 7.7 ± 3.8, $d = 0.97$] was found (Table 4). The proportion of participants with a global score < 5 increased from 0.0% at Baseline to 28.6% (WW: n = 3, WW+ginger: n = 5) at Post.

The sensitivity analyses did not change the overall observation that there was no statistically significant difference in the global PSQI score between WW and WW+ginger over time [**A**: time $F(1,26) = 40.40$, $p < 0.001$, intervention $F(1,22) = 0.01$, $p = 0.92$, interaction $F(1,26) = 2.52$, $p = 0.12$; **B**: time $F(1,24) = 85.51$, $p < 0.001$, intervention $F(1,24) = 0.48$, $p = 0.49$, interaction $F(1,24) = 3.51$, $p = 0.073$].

Table 3
Conditions of the footbath implementation as a function of treatment.

	WW ($n = 13$)	WW+ginger ($n = 15$)	Range	t	p
Number of footbaths	11.1 ± 1.6	11.7 ± 2.3	5–14	0.80	0.43
Minutes before bedtime	110.7 ± 28.2	97.9 ± 42.1	18–420	-0.95	0.35
Initial water temperature, °C	40.2 ± 0.9	40.1 ± 1.1	36.8–43.2	-0.37	0.71
Water-cooling, °C	2.6 ± 0.4	2.4 ± 1.0	0.1–5.6	-0.59	0.56
Duration, minutes	18.3 ± 1.8	19.4 ± 3.4	10–35	1.18	0.25

Data are presented as mean ± SD. WW=footbath with warm water only, WW+ginger=footbath with ginger powder.

Table 4
Descriptive *within*-group changes from Baseline to Post (2 weeks later) for the primary and secondary outcome measures.

	WW			WW+ginger		
	Diff	95% CI	ES	Diff	95% CI	ES
Self-reported sleep quality						
PSQI global score	-4.0	[− 5.4;− 2.6]	1.3	-2.4	[− 4.0;− 0.8]	0.7
ISI total score	-4.2	[− 7.0;− 1.3]	1.0	-3.7	[− 5.6;− 1.9]	0.8
Warmth perception (Herdecke Warmth Perception Questionnaire, HWPQ)						
Face	-0.1	[− 0.7; 0.5]	0.1	0.1	[− 0.2; 0.4]	0.1
Hands	-0.4	[− 1.0; 0.3]	0.4	-0.3	[− 1.0; 0.5]	0.3
Feet	0.0	[− 0.8; 0.8]	0.0	0.5	[0.0; 1.0]	0.6
Overall warmth	-0.4	[− 1.1; 0.3]	0.4	-0.2	[− 0.6; 0.2]	0.3
Distal-proximal skin temperature gradient, in °C						
D1	-0.4	[− 1.4; 0.5]	0.2	-0.6	[− 1.6; 0.5]	0.2
D2	0.6	[− 1.2; 2.4]	0.2	-0.1	[− 1.4; 1.3]	0.0
S1	0.7	[− 1.0; 2.3]	0.3	-0.1	[− 1.6; 1.3]	0.1
S2	0.5	[− 1.2; 2.1]	0.2	-0.3	[− 1.4; 0.8]	0.2
S3	0.0	[− 0.4; 0.4]	0.0	-0.2	[− 0.5; 0.1]	0.4

WW=footbath with warm water only (n = 13), WW+ginger=footbath with ginger powder (n = 15), Diff=mean difference, CI=confidence intervals, ES=Cohen's d effect size, PSQI= Pittsburgh Sleep Quality Index, ISI= Insomnia Severity Index, D1 =day, D2 =sleep preparation, S1 =sleep latency, S2 =begin of sleep, S3 =night. PSQI global score ranges from 0 to 21 (≥5 indicates poor sleep quality). ISI total score ranges from 0 to 28 (0–7 =no, 8–14 =sub-threshold, 15–21 =moderate, and 22–28 =severe insomnia). HWPQ scores range from 0 =cold and 4 =hot.

3.5. Secondary outcome measures

3.5.1. ISI

The effect on the ISI total score did not differ between WW and WW+ginger (Table 2). Both groups improved over time from moderate insomnia at Baseline to sub-threshold insomnia at Post (Table 4).

3.5.2. HWPQ

No differences were found between WW and WW+ginger for the warmth perception of the face, hands, and feet as well as for overall warmth (Table 2). In WW+ginger, warmth perception of the feet increased over time (Table 4). Aside from that, no improvements over time were observed in both groups (Table 4).

3.5.3. DPG

WW+ginger did not have a greater effect on DPG compared to WW (no *between*-group differences, Table 2). No significant improvements over time were found for either group (Table 4). Although DPG increased during sleep preparation (D2), neither group reached values ≥ 0 °C.

4. Harms

Six adverse events occurred in 6 participants. Two participants (WW: $n = 1$, WW+ginger: $n = 1$) reported erythema of the skin of the feet and lower legs immediately after the footbath (WW: after one footbath, WW+ginger: after each footbath), which disappeared within a few minutes. One participant (WW+ginger) reported nausea for up to 30 min following 3 of 11 footbaths. One participant (WW) experienced malaise and circulation problems during the night after her first footbath at 40.5 °C. After consultation, she continued the footbaths at a lower temperature (38–39 °C). She had no further complaints, although she increased the water temperature again on her own initiative (up to 40.5 °C). Finally, two participants (both WW+ginger) reported back pain during the two-week footbath period. One of them required outpatient medical treatment due to a suspected herniated disc or pinched nerve (complaints did not start immediately after a footbath). The other adverse events did not require medical intervention.

5. Discussion

This study showed that among adults with self-reported insomnia symptoms, daily usage of warm ginger footbaths for two weeks had no greater effect on sleep quality (global PSQI score) and insomnia severity (ISI total score) than footbaths with warm water only. Nor were there significant overall differences in perceived warmth (HWPQ) or actual skin temperature (DPG). Both groups, those undertaking two weeks of warm water footbaths or warm footbaths with ginger, improved over time in terms of self-reported sleep quality (PSQI) and insomnia severity (ISI). Perceived warmth of the feet increased only in the ginger footbath condition over time.

The improvement in the global PSQI score is consistent with previous studies.[20,23] Seyyedrasooli and colleagues analyzed the effects of nightly footbaths (20 min at 41–42 °C) for 6 weeks on sleep quality in elderly men (67.49 ± 4.28 years) and observed a reduction in the global PSQI score from baseline 7.30 ± 0.68 to post-intervention 4.13 ± 3.57.[20] Another study, in which nightly footbaths (20 min at 41–42 °C for 6 weeks) were applied in menopausal women (53.42 ± 1.84 years), found a comparable reduction in the global PSQI score from baseline 9.79 ± 3.75 to post-intervention: 5.11 ± 3.07.[23] Kim and colleagues observed that nightly footbaths (30 min at 40 °C for 4 weeks) enhanced the sleep quality by increasing the total sleep amount and sleep efficiency in the elderly (> 65 years), especially in those who had a poor sleep quality at baseline. However, sleep latency did not differ from a placebo (footbaths at 36.5 °C) or control group (no intervention).[19] Interestingly, the effects on sleep quality were highest at week 2 and decreased at week 3 of the footbath therapy.[19] Therefore, the authors suggested administering footbaths for 2 weeks, pausing for a week, and then resuming the therapy afterwards.[19] Among our participants, global PSQI score and ISI total score decreased after 2 weeks, although the decrease in ISI did not correspond to a clinically significant improvement (which requires a reduction by 6 points[52]).

Liao and colleagues examined single applications of warm footbaths (40 min at 41 °C[53] or 20 min at 40 °C [2]) in the elderly and did not find an improvement in perceived sleep quality or polysomnographic sleep compared to non-footbathing nights.[2,53] However, they observed an increase in skin temperature of the feet and DPG after footbaths.[2,53] A subgroup analysis showed that among participants with cold feet at bedtime, a warm footbath not only increased DPG, but also improved polysomnographic sleep (with shortened sleep latency and enhanced sleep efficiency).[2] Therefore, nightly footbaths may only shorten sleep-latency and improve sleep quality in individuals with cold feet.[2]

Among our participants, global PSQI score and ISI total score improved, although we did not find an effect of WW or WW+ginger on DPG. Accordingly, we interpret the observed improvement of insomnia symptoms as either subject to other mechanisms than DPG or that we were not able to accurately measure an effect on DPG with the equipment and our experimental design. In our study, DPG was measured on non-footbathing nights at Baseline and Post. Hence, with the limitations of the available data, it cannot be clarified whether ginger actually led to a greater increase in peripheral blood flow and heightened DPG directly after the footbaths. Other authors have reported increases in DPG to above 0 °C after footbaths.[14,53] However, DPG gradually declined thereafter,[14] and the elevated level did not persist during sleep.[53]

Warmth perception of the feet increased only with WW+ginger over time. The cutaneous vascular response to topical capsaicin (a TRPV1 agonist) was observed to be similar to that of direct local warming in that both generated a sensation of warmth.[35] However, capsaicin sensitizes TRPV1 channels and thereby lowers the threshold for local warming-induced vasodilation in a dose-dependent manner.[35] This amplified response to heat stimuli[35] is also expected with topically administered ginger. In previous studies, a higher and longer-lasting warmth perception of the feet was observed after WW+ginger compared to WW.[29,30,54] Moreover, Therkleson and Sherwood described lasting warmth after ginger compresses.[55] Based on Liao's assumption

that warm footbaths may improve sleep in individuals with cold feet,[2] the addition of ginger powder could provide additional benefits for these patients with respect to well-being because stronger cold perceptions were reported after sleep deprivation.[56] However, taking into account the additional costs of ginger powder (about 2.32€ per footbath), our study did not show clear benefits of ginger in the treatment of insomnia symptoms.

Although footbaths are generally regarded as a safe intervention,[20,23,24] a total of 21% of our study participants experienced adverse events that should be anticipated, monitored and incorporated into patient education. The activation of TRPV1-expressing nociceptors on the skin can cause transient and localized skin reactions at the site of application.[57] Erythema of the skin of the feet and lower legs is triggered by the release of vasoactive peptides[58] and has also been reported in other studies.[29,30] Skin exposure to TRP agonists does not generally pose serious safety concerns,[57,59] however, pain at the application site can cause transient increases in blood pressure which may be of consequence.[57,58] Two of our study participants experienced short-term nausea, malaise or circulation problems, which highlights the necessity of determining footbath conditions based on individual patient needs and requires careful monitoring. To prevent complaints such as back pain, the preparation of footbaths as part of home treatment for insomnia may need to be reconsidered and facilitated, perhaps with the use of less water, that would make footbath preparation less strenuous for patients.

Moreover, the optimal conditions of footbath implementation (water temperature, footbath duration, ginger dose, and treatment duration) to achieve both clinically significant effects and low adverse reactions still need to be determined. It appears that the specific conditions of the prescribed footbaths need to be carefully tailored to the patient's needs and experiences, with monitoring and patient-centered education regarding potential adverse events. In our study, WW+ginger was prepared with a dose of 6.67 g/liter, a dose consistent with clinical routine, and water temperatures between 38 and 42 °C. Other studies have used water temperatures between 40 °C,[2,19] 41 °C[53] and 42 °C.[20,21] The degree of vasodilation is proportional to the temperature used for local warming with a maximum vasodilation occurring at 42 °C.[7] However, footbaths at 42 °C can promote the activity of the sympathetic nervous system.[60] According to Xu and Uebaba, the following footbath water temperatures and durations strike the best balance between safety and comfort: 10 min at 42 °C, 15 min at 40 °C, or 20–25 min at 38 °C.[61] We specified a maximum duration of 20 min and participants were instructed to discontinue the footbath earlier if they felt uncomfortable. The documentation of adherence to this regimen revealed that some participants exceeded the instructed water temperature and duration, which might have precipitate adverse events and influenced the results. This suggests that greater precision of footbath instructions is prudent, and should provide specific water temperature and duration parameters.

It is possible that regular use of footbaths could promote reorganization of sleep and thermoregulation mechanisms, and/or positive rituals, psychological preparation and expectations, thus contributing to restful sleep. However, since we did not include a control (usual care) or placebo group (tepid footbath) we cannot exclude the possibility that improvement in sleep quality over time was triggered by spontaneous improvement, regression to the mean or the Hawthorn effect.[62] Moreover, we did not exclude participants taking phytopharmaceuticals, melatonin, health foods or other drugs for the treatment of sleep disorders. Although the drug intake was similar in both groups and is included in questions of the PSQI, we cannot distinguish the influence of the footbath therapy from the other treatments. Further limitations should be acknowledged. We were not able to perform an exact sample size calculation. Given the small sample size and the exploratory nature, the study may be not adequately powered to detect a difference and results should be interpreted cautiously. Another limitation was the lack of blinding, which might have influenced the self-reported outcome measures. Future studies, for example, might include another strong-smelling herb without known vasodilator properties. Furthermore, we did not measure core body temperature, so we cannot claim that peripheral vasodilation induced by footbaths was associated with an evening decrease in core body temperature. In addition, we did not provide standardized clothing for 24-hour DPG measurement. Nor did participants document physical activity or food intake as part of the protocol. Therefore, it cannot be ruled out that the observed DPG variations were influenced by clothing, food intake (e.g., alcohol, caffeine) or activity level. Food intake can act as a major time cue (termed zeitgeber) for peripheral metabolic tissue clocks.[63] Zeitgebers are factors that allow synchronization (entrainment) between the clocks of the circadian timing system and with the external environment[4] Hence, central and peripheral rhythms may become desynchronized as a result of distinct food intake patterns.[63] Thus, more research is also needed to assess the impact of meal timing on sleep.[63] The performance of the footbaths could not be monitored in real time under strict experimental conditions since the study footbaths were conducted during the pandemic in the participants' homes. That said, the authenticity of the home environment for data collection revealed real-world considerations and challenges for footbath administration. The strictness and standards of the protocol were necessarily affected under these conditions and may have influenced the findings. We did not assess ambient conditions (such as room temperature and humidity) during the footbaths, nor did we inquire whether participants used a fan during sleep, although this may have influenced foot temperature and heat emission.[5,11,64]

The fact that the study was able to be carried out in home settings bodes well for the feasibility of footbaths to be incorporated as part of home treatment for insomnia symptoms. Further strengths of the study are the randomized vehicle-controlled design and the use of valid patient-reported outcome measures. Although sleep architecture[2] and the ability to warm the peripheral skin[12] changes with age, the inclusion of participants of a wide age range and with insomnia symptoms can be considered as a strength of the study. Previous research has been conducted almost exclusively on the elderly[2,19,20,23,53] without screening for sleep disturbance or insomnia symptoms as eligibility criteria.[2,19,20,23]

In conclusion, the dose of ginger selected for our study did not add meaningfully to warm water footbaths in terms of reduction in global PSQI score or ISI total score over time. Nor did the added ginger have a greater effect on participants' warmth perception or DPG. Considering the effect sizes, costs and risks, the recommendation for patients with self-reported insomnia symptoms would be to perform nightly warm water footbaths without the addition of ginger powder. However, particular patients, with problems falling asleep and who experiences cold feet at bedtime, could potentially benefit from the addition of ginger powder. Further research is needed with an adequately powered sample size incorporating a control or placebo group to fully assess the impact of footbaths, and the addition of ginger. Incorporating measurements of core body temperature and polysomnographic sleep into the study design could help provide further insight into mechanisms of action.

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Ethics approval and consent to participate

The study was approved by the Ethics Committee of the Medical Association of Baden-Württemberg in Stuttgart, Germany (F-2019–112). We obtained written informed consent from all participants.

CRediT authorship contribution statement

Silja Kuderer: Conceptualization, Methodology, Formel analysis,

Investigation, Data curation, Writing - original draft; **Katrin Vagedes**: Conceptualization, Methodology, Writing - review & editing; **Henrik Szöke**: Supervision, Writing - review & editing; **Matthias Kohl**: Supervision, Formel analysis, Writing - review & editing; **Stefanie Joos**: Supervision, Writing - review & editing; **Peter W. Gündling**: Supervision, Writing - review & editing; **Jan Vagedes**: Conceptualization, Methodology, Writing - review & editing.

Competing interests

The authors have no conflicts of interest relevant to this article to disclose.

Availability of data and materials

Deidentified individual participant data that underlie the results reported in this article will be made available. The data will be made available beginning three months and ending five years following article publication to researchers who provide a methodologically sound proposal for use in achieving the goals of the approved proposal. Proposals should be submitted to j.vagedes@arcim-institute.de.

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