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CLINICAL REVIEW

Before-bedtime passive body heating by warm shower or bath to improve sleep: A systematic review and meta-analysis

Shahab Haghayegh [a, *], Sepideh Khoshnevis [a], Michael H. Smolensky [a, b], Kenneth R. Diller [a], Richard J. Castriotta [b, c]

[a] Department of Biomedical Engineering, Cockrell School of Engineering, The University of Texas at Austin, USA
[b] Department of Internal Medicine, Division of Pulmonary and Sleep Medicine, McGovern School of Medicine, The University of Texas Health Science Center at Houston, USA
[c] Department of Medicine, Division of Pulmonary, Critical Care and Sleep Medicine, Keck School of Medicine, University of Southern California, Los Angeles, USA

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SUMMARY

Water-based passive body heating (PBH_{WB}) as a warm shower or bath before bedtime is often recommended as a simple means of improving sleep. We searched PubMed, CINAHL, Cochran, Medline, PsycInfo, and Web of Science databases and extracted pertinent information from publications meeting predefined inclusion and exclusion criteria to explore the effects of PBH_{WB} on sleep onset latency (SOL), wake after sleep onset, total sleep time, sleep efficiency (SE), slow wave sleep, and subjective sleep quality. The search yielded 5322 candidate articles of which 17 satisfied inclusion criteria after removing duplicates, with 13 providing comparable quantitative data for meta-analyses. PBH_{WB} of 40–42.5 °C was associated with both improved self-rated sleep quality and SE, and when scheduled 1–2 h before bedtime for little as 10 min significant shortening of SOL. These findings are consistent with the mechanism of PBH_{WB} effects being the extent of core body temperature decline achieved by increased blood perfusion to the palms and soles that augments the distal-to-proximal skin temperature gradient to enhance body heat dissipation. Nonetheless, additional investigation is required because the findings regarding PBH_{WB} are limited by the relative scarcity of reported research, especially its optimal timing and duration plus exact mechanisms of effects.

Introduction

Bathing has long been linked not only with cleanliness and spiritual and religious purification [1] but health preservation and rehabilitation [2]. During the Homeric era of 1200 to 800 BC bathing was viewed exclusively as hygienic [2]; however, Hippocrates (460–370 BC) regarded it as health promoting and therapeutic. The Romans also considered it to be curative, in addition to relaxing and pleasurable [2]. During the 16th century, bathing, especially in spring waters, was pursued for healing, and commencing in the 19th century spas specializing in hot and cold mineral baths, commonly combined with mud packs, physical exercise, massage, and special diets, became popular as a holistic remedy of diverse maladies [2]. Indeed, at this time warm baths were extensively extolled for their healthful benefits, being advocated, for example, in the United States by Dr. John Gunn in his popular home medical handbook, 'Gunn's Domestic Medicine' [3]. However, there seems to be no evidence warm or hot baths were specifically used to facilitate or improve sleep until the 20th century, as reviewed by Raymann et al. [4].

In this context, the relationship between blood distribution, body temperature, and states of sleep and wakefulness has long been of interest. The Greek philosopher Alcmeaon of Croton, ~500 BC, associated the state of sleep with the withdrawal of blood from the periphery to the larger "blood-flowing" vessels and waking with its "rediffusion" [5], and the 7th century essayist Robert Burton wrote "A hot brain does not sleep" [6]. In the 19th century Davy and Jürgensen described the human temperature circadian rhythm characterized by elevated daytime and depressed nighttime level

* Corresponding author. Department of Biomedical Engineering, 107 W Dean Keeton St, Austin, TX, 78712, USA.
E-mail address: shahab@utexas.edu (S. Haghayegh).

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Abbreviations

AVA	arteriovenous anastomoses
CBT	core body temperature
CI	confidence interval
ΔCBT	attenuation in core body temperature
DPG	distal-to-proximal skin temperature gradient
EEG	electroencephalography
EMG	electromyography
EOG	electrooculography
ES	effect size
h	hour
ICU	intensive care unit
JBI	Joanna Briggs Institute
min	minutes
OSAQ	Oguri-Shirakawa-Azumi questionnaire
PBH	passive body heating
PBH_{WB}	water-based passive body heating
PRISMA	preferred reporting items for systematic reviews and meta-analysis
PSG	polysomnography
RCT	randomized control trial
REM	rapid eye movement
SE	sleep efficiency
SOL	sleep onset latency
SWS	slow wave sleep
TBI	traumatic brain injury
TST	total sleep time
WASO	wake after sleep onset
y	year

[7,8], and Dalton elucidated the "normal variations of temperature in the living body", with differences between central and peripheral sites [9]. Collectively, these theoretical conceptualizations and scientific discoveries laid the foundation for contemporary investigations substantiating association between sleep and decline at the end of the activity span of core and brain temperature achieved by circadian rhythms governing the dissipation of body heat [10–13]. Accordingly, alteration of the temperature circadian rhythm, e.g., by disease, work schedule, and transmeridian travel, is commonly associated with episodic or chronic insomnia – prolonged sleep onset latency (SOL) and/or poor sleep maintenance [14–18]. The estimated prevalence of insomnia of various etiology, including that directly or indirectly associated with perturbed temperature circadian rhythm, is substantial, being 1.5-fold higher in women than men and much higher in the elderly than young [4,19–23]. The consequent sleep deprivation compromises quality of life and productivity and increases vulnerability for accidents and injury [24]. Moreover, it is implicated as a cause or effect of psychiatric, cardiovascular, metabolic, and other medical conditions, whose healthcare expenditures globally amount to billions of dollars annually [19,21,25].

Water-based passive body heating (PBH_{WB}) accomplished by warm/hot showers or body or foot bathing is often recommended as a simple and low-cost nonpharmacological means of managing insomnia [26–28]. Such advice largely derives from findings of questionnaire and observation-based investigations. For example, Aritake-Okada et al. [29] found bathing to be an effective means of improving nighttime sleep and decreasing excessive daytime sleepiness; Ojima et al. [30] reported good subjective sleep quality of persons who regularly bathe; Hayasaka et al. [31] detected positive relationship between frequent bathing and self-assessed sleep quality and Goto et al. [32] likewise demonstrated positive association between frequent bathing combined with onsen (hot springs) facilities and self-rated sleep quality; and Camilleri and Barrett [33] observed better sleep of seniors with late-day bathing. Findings of objective laboratory studies complement the positive effects of PBH_{WB} inferred by subjective measures. Yu et al. [34] found footbath PBH_{WB} more acceptable by men than women and more effective in winter than summer; Raymann et al. [35] showed skin temperature manipulation by PBH_{WB} strongly influences amount of rapid eye movement (REM) and slow wave sleep (SWS); and Deguchi et al. [36] described immediate (after 2 wk) and more substantial long-term (after 4–6 wk) improvement in sleep, along with reduction in restlessness, wandering, and/or aggression, in 60–90% of a small cohort of senile dementia patients when bathed twice weekly in the early evening (18:00–19:00 h) than early afternoon (14:00–15:00 h). Nonetheless, while many investigations demonstrate improvement of various sleep parameters by evening or before bedtime PBH_{WB} treatment, some do not [4,37,38]. The goal of this article is to review the published research concerning the potential beneficial effects of PBH_{WB} on nighttime sleep and proposed mechanisms.

Methods

The review was conducted in adherence with the Preferred Reporting Items for Systematic Review and Meta Analyses (PRISMA) statement [39]. The PRISMA checklist is provided in Appendix A.

Search strategy

We performed online searches in April 2018 of PubMed, CINAHL, Cochran, Medline, PsycInfo, and Web of Science databases, without restriction of date or language of publication, using the keywords and their combinations presented in Table S1 to retrieve studies pertaining to sleep outcomes of bath and shower PBH_{WB} interventions. References of qualifying investigations and related review papers were additionally examined for eligible publications. An example of the strategy used for the PubMed search is illustrated in Appendix B of the supplementary materials.

Eligibility criteria

Inclusion of retrieved publications for systematic review required satisfaction of the following criteria: 1) full-night investigation of the effect of PBH_{WB} on sleep quality and/or sleep parameters, 2) body heating by a water-based, i.e., showering or bathing, method alone, and 3) report of original data and findings of statistical analyses. Exclusion criteria were: 1) continued body warming during sleep, 2) unreported or insufficient details of investigative methods or results, 3) unspecified interval of time between PBH_{WB} treatment and bedtime, 4) absence of information on duration of PBH_{WB}, 5) lack of information on temperature of the intervention, 6) PBH_{WB} combined with another treatment, 7) non-provision of control or baseline data, 8) treatment other than water-based methods of showering or bathing, such as heating blankets, 9) duplicate report based on same data, and 10) published review of the literature. The same inclusion and exclusion criteria were also used for meta-analysis of retrieved publications specifically relating to sleep parameters. However, the variable of "subjective sleep quality" and the studies where sleep parameters were measured by questionnaire or interview check list were excluded from meta-analyses. This is because the scoring system and range of the diverse methods utilized in the different studies are dissimilar and not quantitatively comparable. Nonetheless, we include the findings of these studies in our systematic review, since they provide valuable perspective about the utility of PBH_{WB} as a sleep aid.

Study selection

Retrieved citations were imported into Mendeley reference manager software. After removal of redundant reports from search of the multiple databases, irrelevant publications were eliminated by review of titles, abstracts, and keywords by one of the authors (SH). Full text review of all remaining published articles was accomplished independently by two authors (SH and SK). Decisions regarding eligibility of investigations were based on the above-outlined *a priori* established inclusion and exclusion criteria, and reasons for exclusion were recorded. Disagreements were resolved by discussion. Three studies trialed two different temperatures; in this case the resulting data of only the highest (≥40 °C) temperature intervention were included in meta-analyses.

Data extraction and data items

A data extraction sheet was developed and revised after pilot-testing on five randomly selected eligible studies. One author (SH) extracted data and a second (SK) checked accuracy. The following particulars were extracted: first author and year of publication; research questions/study aims; number, type, sex, and age of subjects; temperature, method, and duration of PBH_{WB} intervention; interval between application of PBH_{WB} treatment and bedtime; mode of sleep assessment, and effect of PBH_{WB} therapy on SOL, wake after sleep onset (WASO), total sleep time (TST), sleep efficiency (SE), slow wave sleep (SWS), and subjective sleep quality.

Bias assessment (Tables S2 and S3)

Each included study was independently evaluated for risk of bias due to deficiencies of investigative methods and procedures using the Joanna Briggs Institute (JBI) checklist for quasi-experimental studies [40]. Adapted JBI checklists were applied for randomized control trials (RCT) [40] and prospective cohort studies [41]. We additionally created a checklist for crossover studies based on JBI recommendations for RCT [40]. Disagreements between raters were resolved by discussion.

Statistical analysis

For studies amenable to meta-analysis, effect size (ES, Cohen's d) of the sleep parameters of SOL, WASO, TST, SE, and SWS was calculated by deriving the mean difference between the baseline and treatment nights and dividing it by the pooled standard deviation [42]. Some trials reported values for each experimental night or individual groups of subjects rather than aggregate ones; in these cases, we combined or pooled data to derive a single mean and standard deviation per experimental, i.e., baseline and $PHB_{WB,}$ condition [43,44]. A positive ES infers lower value of a given parameter on baseline than treatment nights. ES values equal to 0.2, 0.5, and 0.8 are considered, respectively, small, medium, and large effects [45]. We used a random effect model to calculate the summary effect per evaluated sleep parameter [44]. $P < 0.05$ is considered sufficient evidence to reject the null hypothesis ES equals zero. Presence of heterogeneity was assessed by calculation of the Q statistic, which follows the χ^2 distribution. The null hypothesis for this test is all studies share a common ES [44]. The derived τ^2 and I^2 statistics represent, respectively, the overall variance of the true effect size and proportion of observed variance indicative of the actual variation among studies [44]. When heterogeneity was substantiated, potential explanations were explored *post hoc* by both random-effect subgroup and meta-regression analyses [44]. Subgroup analysis assesses the disparity across subgroup effects relative to the precision of the difference in values for variables of interest within subgroups [44]. The precision of this difference is affected by within-study variance and total number of subjects, between-study variance and total number of studies, and between-subgroup variance and number of subgroups [46]. Several studies and guidelines [47–49] recommend the meta-regression method as a more advance approach of higher statistical power compared to subgroup analysis [50] to evaluate potential significance of independent categorical effect-modifier variables. Moreover, this method allows us to simultaneously investigate the effect of multiple effect modifiers [47]. As recommended, we used a cut-off of 10% ($P = 0.1$) for testing the significance of heterogeneity and also for subsequent *post-hoc* evaluation of effect modifiers [51,52]. Forest plots, i.e., graphical display of findings of individual investigations plus composite overall findings per sleep parameter, were created by Microsoft® Excel for Mac (version 16.8, Microsoft Corporation, Redmond, Washington, USA). The meta-regression was done using R (R Core Team, 2018). Publication bias was assessed by the funnel plot regression method [53] for all sleep parameters using STATA software (version SE 14.2, StataCorp LLC, College Station, Texas, USA).

Results

Search results

The flow diagram of Fig. 1 depicts the PRISMA-based process of selecting investigations of relevance utilizing the search words depicted in Table S1. A total of 5316 publications were retrieved, of which 1451 were replicates. Six additional publications were identified through reference lists or other sources. Abstracts of the potentially relevant 3865 total publications were individually screened, yielding 121 for full text appraisal, of which 17 met all inclusion criteria. Some 13 [37,38,54–64] of the qualifying 17 investigations enabled quantitative synthesis and meta-analyses. One of these studies utilized two – body and foot bath – PBH_{WB} treatments, thereby increasing the number of possible comparisons to 14.

Overview of included studies (Table 1)

Study design

Of the 17 studies that met inclusion criteria, 11 were designed as a crossover [37,38,54–58,60–63], three as a quasi-experimental [59,65,66], one as a randomized control [67], and two as a prospective [64,68] cohort trial.

Study population

Participants of the 17 investigations, which entailed 18 PHB_{WB} trials in total, were diverse, ranging from young healthy soccer athletes to middle-age traumatic brain injury (TBI), older sleep apnea, sleep disturbed, acute coronary syndrome, intensive care unit (ICU), insomniac, and cancer patients. Sample size varied markedly among the trials, from five to 70 subjects (median = 13), with six of them (~35%) involving more than 20 subjects. The average age of participants also varied greatly: older than 40 y in 12 studies, with six of them greater than 60 y.

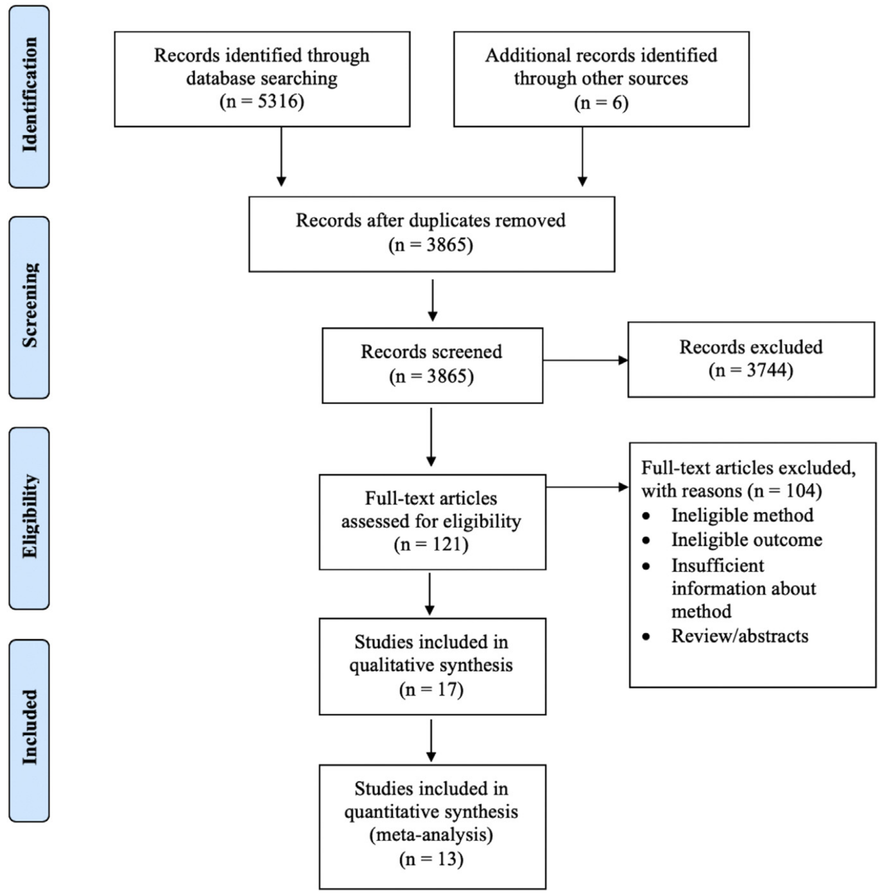

Fig. 1. Flow diagram adapted from Moher et al. [39] describing the search strategy of the different databases using the terms outlined in Table S1 and as exemplified in Appendix B.

Nature of PBH_{WB} interventions

PBH_{WB} was achieved by shower in one study, footbath in nine, body bath in six, and both body bath and footbath in one. Water temperature in 16 of the 18 experiments varied from 40 to 42 °C, with those of two studies testing two different temperatures. PBH_{WB} commenced and ended 1–2 h before bedtime in five trials, and it commenced and ended 1 h or less or 2 h or more before bedtime in thirteen trials. PBH_{WB} in nine trials lasted 20 min or less and lasted more than 20 min in nine trials.

Sleep assessment methods

Polysomnography (PSG) entailing electroencephalography (EEG), electromyography (EMG), and electroocugraphy (EOG) was utilized in nine studies, wrist actigraphy in five studies, self-assessment questionnaires in nine studies, and observation check list and home-sleep tracker each in one study. Most (~65%) investigations relied only on one of these methods.

Sleep outcomes

Sleep onset latency (SOL)

Fig. 2 presents the forest plot of effect size plus overall pooled estimated effect size for the individual 11 PBH_{WB} trials in which SOL was objectively assessed. The pooled estimate reveals PBH_{WB} achieved significant decrease of SOL independent of the temperature, duration, and interval of time before bedtime of its scheduling (mean of baseline nights 24.6 min vs. mean of PBH_{WB} nights 17.4 min; ES: −0.43; 95% CI = −0.76 to −0.10; P = 0.010). Studies that utilized questionnaire and/or observation checklist methods also reported PBH_{WB} improved SOL [66,67]. As recommended, we used a cut-off of P = 0.1 when conducting heterogeneity analyses for between-subgroup differences [51,52]. The test of heterogeneity for findings of the studies assessing SOL rejected the null hypothesis of shared common ES (P = 0.088), and the test for publication bias was insignificant (P = 0.604).

The finding of heterogeneity in the ES of studies entailing objective assessment of SOL prompted *post hoc* exploration of two hypotheses to explain its origin. First, we hypothesized an important source of variation in ES derives from difference across trials in the interval of time between the application of PBH_{WB} and bedtime. We tested this hypothesis by categorizing the 11 trials into two groups: 1) those in which PBH_{WB} commenced and ended 1–2 h before bedtime (N = 2) and 2) those in which PBH_{WB} commenced and ended 1 h or less plus those in which PBH_{WB} commenced and ended 2 h or more before bedtime (N = 9). The random effect model Q test for heterogeneity with separate estimate of τ^2 [44] reveals significant difference in effect size between the two groups (χ^2 = 7.42, df = 1, P = 0.006), thereby indicating the timing of PBH_{WB} 1–2 h before bedtime is associated with statistically significant shortening of SOL. Second, we evaluated the hypothesis the duration of PBH_{WB} acts as an effect modifier upon SOL. The duration of PBH_{WB} across the 11 trials ranged between 10 min to three successive blocks each of 30 min, i.e., 90 min in total. We categorized the 11 trials into two groups, ones (N = 4) that applied PBH_{WB} for shortest duration, i.e., 10–20 min, and ones (N = 7) that applied PBH_{WB} for longest duration, i.e., 20–90 min. However, as reported in Table 2 no statistically significant between-group difference in effect on SOL is detected according to duration of PBH_{WB} (χ^2 = 1.01, df = 1, P = 0.314). We

Table 1
Characteristics of the included studies.

Author (y)	Research question	Measurements	Subjects		PBH_{WB} application				Sleep assessment
			N (%female)	Age, range $\bar{x} \pm$ SD	water temp °C	Time before bedtime	Duration	Body site	
Cherian (2012) [66]	Effect of footbath on SOL and relaxation score in cancer pts	five baseline nights + five treatment nights	40 (62)	40–70	40–45	30 min	15 min	Feet (up to half of lower leg)	Observation check list
Chiu et al. (2017) [57]	Effect of footbath on SOL of traumatic brain injury (TBI) pts	three baseline nights + three treatment nights	23 (65)	35.9	40	1–2 h	30 min	Feet (above ankle)	Act
Dorsey et al. (1996) [58]	Effect of PBH_{WB} on sleep quality of elderly insomniacs	two sets of four nights each: two baseline + either two nights of hot bath or two nights of warm bath	9 (100)	60–72/ 65.1 ± 3.3	40–40.5/ 37.5–38.5	1.5 h	30 min	To mid-thorax level	Act, PSG, QNR
Dorsey et al. (1999) [59]	Effect of PBH_{WB} on CBT-sleep association of older insomniacs	two baseline nights + two treatment nights	14 (100)	60–73/ 64.3 ± 3.5	40–40.5	1.75–2 h	30 min	To mid-thorax level	Act, PSG, QNR
Dowdell and Javaheri (1992) [37]	Effect of external PBH_{WB} on REM and SWS of sleep apnea pts	one baseline night + one treatment night	7	59 ± 4.5	41	2.5 h	30 min	Up to the upper chest level	PSG
Furushima et al. (2009) [60]	Effect of footbath on inpatients complaining of sleeplessness	one baseline night + one treatment night	10 (0)	43–70/ 55.4 ± 8.6	40.1 ± 0.6	30 min	15 min	Feet (below ankle)	Act, QNR
Horne and Reid (1985) [61]	Effect of warm bath on nighttime sleep	three baseline nights + one warm bath night + one cool bath night	6 (100)	20–23	41.0/35.5	≥5 h	3 blocks of 30 min	To mid-thorax level	EEG, EMG, EOG
Jordan et al. (1990) [62]	Comparative effect of change vs. rate of fall in CBT on SWS	three baseline nights + three treatment nights	5 (0)	20.4 ± 1.5	42–43	5.75 h	2 blocks of 40 min	To neck level	EEG, EMG, EOG
Liao et al. (2008) [63]	Effect of warm footbath on CBT, DPG, and sleep	one baseline night + one treatment night	15 (60)	60–75/ 67.4 ± 5.1	41	1 h	40 min	Feet (20 cm above ankle)	PSG
Liao et al. (2013) [38]	Effect of footbath on CBT and sleep quality in elderly	one baseline night + one treatment night	25 (52)	59.8 ± 3.7	40.0 ± 0.5	50 min	20 min	Feet (20 cm above ankle)	PSG
Mishima et al. (2005) [64]	Effect of PBH_{WB} on sleep, circadian phase, and thermoregulation of elderly vascular dementia insomniacs	three baseline nights + two treatment nights + one follow up night	13 (85)	76.9	40.0 ± 0.05	2 h	30 min	To mid-thorax level	Act
Namba et al. (2012) [54]	Effect of footbath on sleep of ICU pts	one baseline night + one treatment night	6 (50)	65 ± 5	40	before bedtime	10 min	Feet (up to the ankle)	PSG, QNR
Rahmani et al. (2016) [65]	Effect of footbath and/ or reflexology massage on sleep quality of acute coronary syndrome pts	two treatment nights + one baseline night	Control: 35 (0) Treatment: 35 (0)	Control: 61.3 ± 11.4 Footbath: 59.6 ± 11.6	40	before bedtime	10 min	Feet (10 cm above ankle)	QNR
Seyyedrasooli et al. (2013) [67]	Effect of footbath on sleep of elderly	6 wk treatment	Control: 23 (0) Treatment: 23 (0)	60–75/Control: 67.5 ± 4.3 Treatment: 66.8 ± 3.8	41–42	1 h	20 min	Feet	QNR
Sung and Tochihara (2000) [55]	Effect of body bath and hot footbath on sleep quality of healthy subjects in winter	one night baseline + one night footbath + one night bath	9 (100)	21–40/26.9	Bath: 40 Footbath: 42	50 min	Bath: 20 min Footbath: 30 min	Bath: up to shoulder Footbath: up to knee	EEG, EMG, EOG, QNR
Whitworth-Turner et al. (2017) [56]	Effect of warm shower before bedtime on sleep of youth soccer players	three nights baseline + three nights treatment	11 (0)	18 ± 1	40	20 min	10 min	Whole body	Home sleep tracker, QNR
Yang et al. (2010) [68]	Effect of footbath on sleep quality and fatigue of chemotherapy-treated gynecologic cancer pts	Subjects followed up during four series of chemotherapy for 6 mo	Control: 25; Treatment: 18	Control: 50.6 ± 11.5 Treatment: 47.1 ± 11.2	41–42	<80 min	20 min	Feet (10 cm above ankle)	QNR

Act: actigraphy; CBT: core body temperature; DPG: distal to proximal gradient; EEG: electroencephalography, EOG: electrooculography, EMG: electromyography; min: minutes; N: number; PBH_{WB}: water-based passive body heating; QNR: questionnaire; y: year.

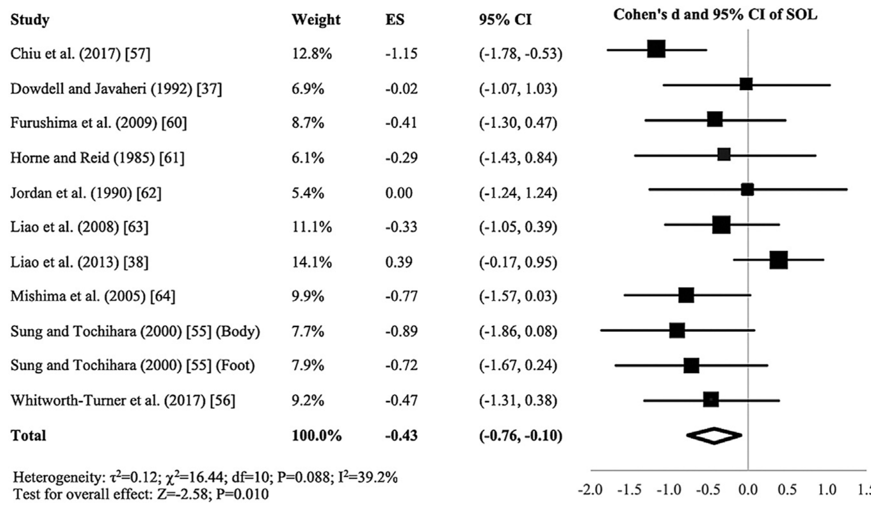

Fig. 2. Forest plot of standardized mean difference (Cohen's d) between treatment and baseline nights of sleep onset latency (SOL). Results are shown as effect size (ES) and 95% confidence interval (CI). Size of the individual symbol markers is indicative of the weight of the respective studies.

Table 2
Role of before-bedtime timing and duration of PBH_{WB} on SOL Shortening[a].

Before bedtime PBH_{WB} application	Summary of effect			Heterogeneity test			
	ES (95% CI)	Z	P	τ^2	I^2	χ^2 (df)	P
Interval <1 h or >2 h vs. baseline	−0.21 (−0.51, 0.08)	−1.44	0.150	0.01	3.1%	8.25 (8)	0.409
Interval 1–2 h vs. baseline	−1.01 (−1.50, −0.52)	−4.02	<0.001	0	0%	0.56 (1)	0.455
Between two group comparison: χ^2 = 7.42, df = 1, P = 0.006 favoring PBH_{WB} 1–2 h before bedtime							
Duration 10–20 min vs. baseline	−0.26 (−0.85, 0.33)	−0.87	0.387	0.20	54.7%	6.63 (3)	0.085
Duration >20 min	−0.61 (−0.94, −0.28)	−3.62	<0.001	0.01	2.7%	6.16 (6)	0.405
Between two group comparison: χ^2 = 1.01, df = 1, P = 0.314 showing no effect of PBH_{WB} duration							

[a] ES: effect size; CI: confidence interval.

further evaluated the source of heterogeneity by conducting a random-effect model meta-regression analysis that simultaneously included both effect modifiers – duration of PBH_{WB} and interval of time between the application of PBH_{WB} and bedtime – categorized in the same manner as done for the subgroup analyses. It yielded the same conclusion, i.e., significant effect of timing ($P = 0.075$, i.e., below the cut-off of $P = 0.1$ recommended for evaluation of effect modifiers) and no significant effect according to duration ($P = 0.822$). We also attempted to evaluate the water temperature as an effect modifier; however, the range of water temperature across the 11 trials was too small, mostly 40 °C (N = 6) and 41 °C (N = 3), for conduct of a meaningful statistical analysis.

Wake after sleep onset (WASO)

Fig. 3 shows the forest plot of the nine investigations in which the WASO variable was explored. The pooled estimate of all studies indicates non-significant improvement by PBH_{WB} in WASO relative to baseline conditions (mean of baseline nights 49.2 min vs. mean

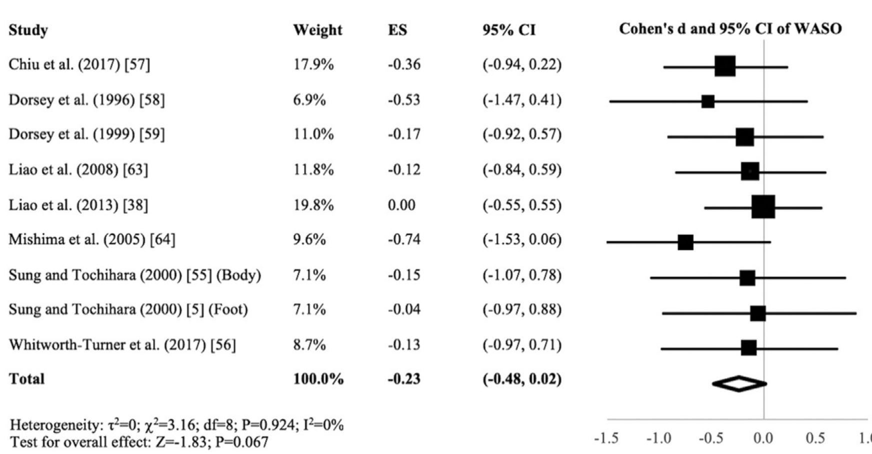

Fig. 3. Forest plot of standardized mean difference (Cohen's d) between treatment and baseline nights of wake after sleep onset (WASO). Results are shown as effect size (ES) and 95% confidence interval (CI). Size of the individual symbol markers is indicative of the weight of the respective studies.

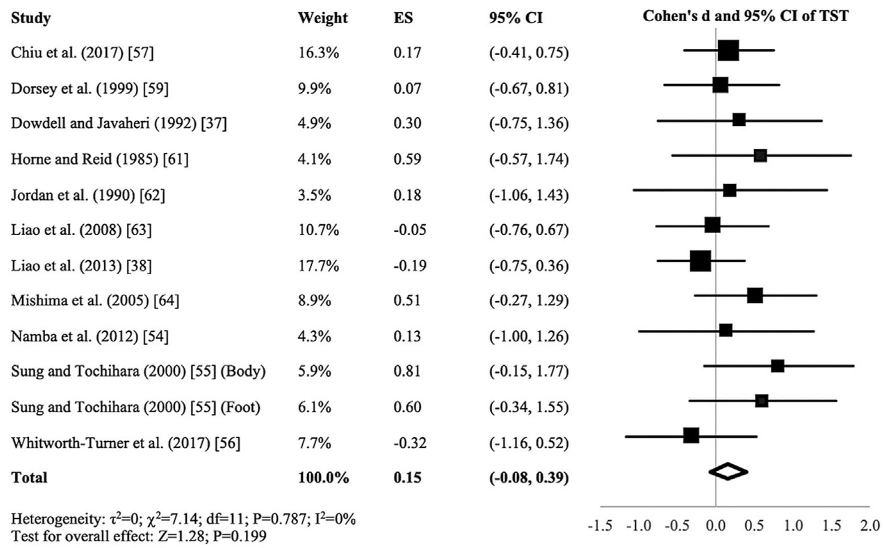

Fig. 4. Forest plot of standardized mean difference (Cohen's d) between treatment and baseline nights of total sleep time (TST). Results are shown as effect size (ES) and 95% confidence interval (CI). Size of the individual symbol markers is indicative of the weight of the respective studies.

of PBH_{WB} nights 41.3 min; ES: −0.23; 95% CI = −0.48 to 0.02; P = 0.067). The test for heterogeneity fails to reject the null hypothesis the studies share a common ES (P = 0.924), and the test for publication bias was not significant (P = 0.534).

Total sleep time (TST)

Fig. 4 displays the forest plot of the 10 different trials in which TST was measured. The pooled estimate discloses non-significant improvement by PBH_{WB} in TST relative to baseline conditions (mean of baseline nights 389.0 min vs. mean of PBH_{WB} nights 395.1 min; ES: 0.15; 95% CI = −0.08 to 0.39; P = 0.199). The test for heterogeneity fails to reject the null hypothesis the studies share a common ES (P = 0.787), and the test for publication bias was not significant (P = 0.091).

Sleep efficiency (SE)

Fig. 5 depicts the forest plot of the 11 different trials in which SE was evaluated. The pooled estimate reveals significant improvement by PBH_{WB} in SE (mean of baseline nights 83.1% vs. mean of PBH_{WB} nights 84.9%; ES: 0.26; 95% CI = 0.02 to 0.51; P = 0.035). This finding based on objective assessment of SE is in line with that of Seyyedrasooli et al. [67], who measured SE by questionnaire; they found a tendency of improved SE by PBH_{WB} relative to control conditions. The test for heterogeneity fails to reject the null hypothesis the studies share a common ES (P = 0.500), and the test for publication bias was insignificant (P = 0.212).

Slow wave sleep (SWS)

Fig. 6 conveys the forest plot of the 10 trials in which SWS was examined. The pool estimate shows non-significant increase in SWS by PBH_{WB} relative to the baseline condition (mean of baseline nights 33.6 min vs. mean of PBH_{WB} nights 40.3 min; ES: 0.23; 95% CI = −0.13 to 0.60; P = 0.213). The test for heterogeneity fails to reject the null hypothesis the studies share a common ES (P = 0.279), and the test for publication bias was not significant (P = 0.057).

Subjective sleep quality

Subjective sleep quality assessed by diverse methods was found to be improved by PBH_{WB} interventions in eight trials [54,55,58–60,65,67,68] and unaffected in one trial [56]. Meta-

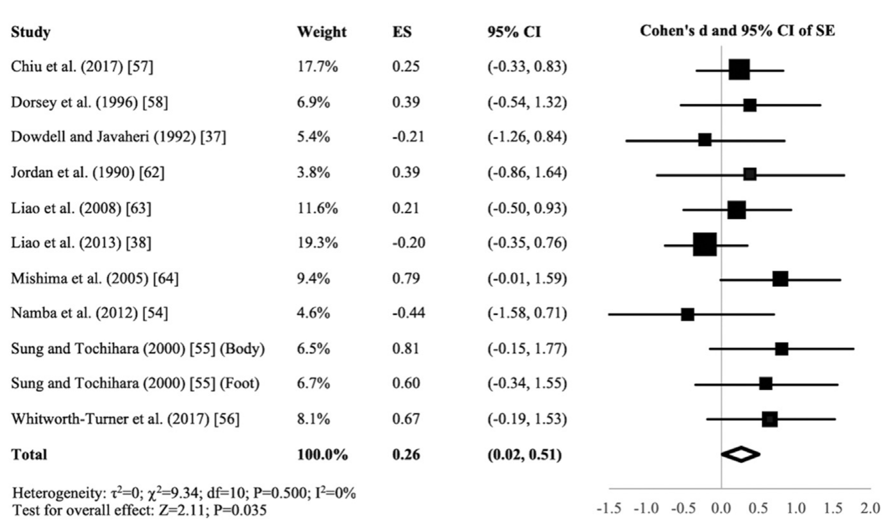

Fig. 5. Forest plot of standardized mean difference (Cohen's d) between treatment and baseline nights of sleep efficiency (SE). Results are shown as effect size (ES) and 95% confidence interval (CI). Size of the individual symbol markers is indicative of the weight of the respective studies.

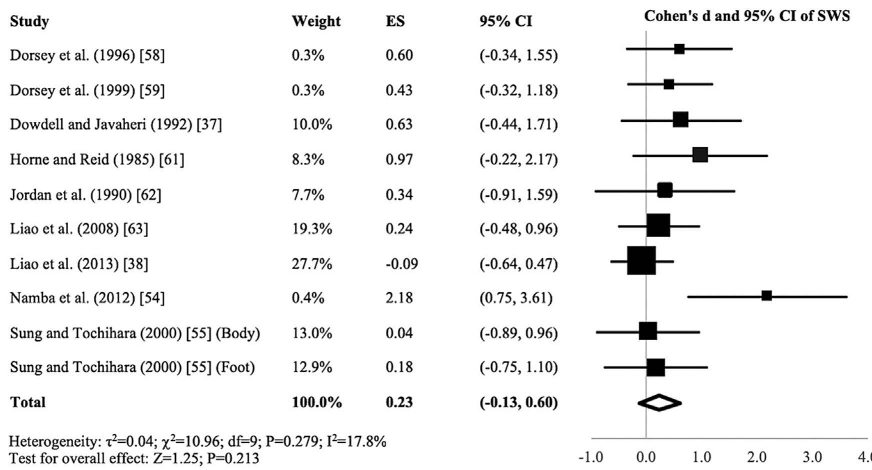

Fig. 6. Forest plot of standardized mean difference (Cohen's d) between treatment and baseline nights of time spent in slow wave sleep (SWS). Results are shown as effect size (ES) and 95% confidence interval (CI). Size of the individual symbol markers is indicative of the weight of the respective studies.

analysis of the data of these trials was not feasible due to application of greatly disparate methods to quantify sleep quality that varied numerically in scale and range of scores. One study involved an interview method [54], one study Oguri-Shirakawa-Azumi) questionnaire (OSAQ) [55], two studies Post Sleep Inventory questionnaire [58,59], two studies Veran Snyder Halpern questionnaire [65,68], one study OSAQ sleep inventory for middle age and aged version [60], one study Pittsburgh Sleep Quality Index questionnaire [67], and one study Consensus sleep diary [56].

Bias assessment

Table S2 summarizes the appraisal by JBI check list for quasi-experimental studies of the methods and conduct of each PBH_{WB} investigation. The major deficiency of most of them is lack of follow-up assessment. Additional ones are incomplete or inappropriate statistical methods, i.e., absence of power analysis, effect size, and/or other relevant calculations, insufficient information regarding reliability of measurements, and inappropriate control group. Studies lacking a control group, before-treatment baseline, and/or appropriate detailed description of experimental methods according to the inclusion and exclusion criteria (Fig. 1) had already been eliminated during the screening process. The only qualifying RCT was that of Seyyedrasooli et al. [67]. It adhered to all requirements for a RCT, except blinding of subjects, examiner, and data analysis personnel. Compliance with the first two requirements was impossible due to the nature of the treatment, but noncompliance with the latter might have been a source of bias (Table S3). Almost all of the crossover trials randomized subjects for order of baseline and treatment procedures; however, less than half of them incorporated a wash-out period of one to seven nights between the two experimental conditions. The deficiencies of non-randomized order of treatment, absence of non-treatment baseline nights, and lack of wash-out period are risks for carry-over bias (Table S3). Finally, the investigation of Yang et al. [68] failed to report a reliable measure of the temperature of the PHB_{WB} intervention, thereby potentially introducing bias into the interpretation of findings (Table S3).

Discussion

A warm shower or foot or body bath before bedtime is often suggested by medical and paramedical professionals to improve sleep [26–28]. The beneficial effect of such interventions has been researched in various settings utilizing a variety of measures, ranging from subjective self-report questionnaires and objective check lists to wrist actigraphy/home sleep trackers to clinical PSG. Many, but not all, of the diverse investigations report significant improvement in objectively assessed sleep parameters and/or subjectively rated sleep quality and sleep parameters. Thus, an aspect of our review of the literature included identification of factors associated with successful improvement of sleep by PBH_{WB} treatments.

Our meta-analyses reveal PBH_{WB} tends to improve SOL, WASO, TST, SWS, and SE; although a statistically significant effect was verified only upon SOL and SE. The largest and most statistically significant effect was attenuation of SOL, on average by 8.6 min (~36%) from that of baseline nights, when applied 1–2 h before bedtime. A major finding regarding SOL across the 17 reviewed studies is the optimal interval of time of 1–2 h between PBH_{WB} intervention and customary bedtime. However, this finding is based upon data of only two investigations that entailed a total of 36 subjects – elderly insomniac subjects with mild to moderate vascular dementia whose average age was 77 y in one study [64] and traumatic brain injury (TBI) patients whose average age was 36 y in the other study [57]. Nonetheless, the findings based on these two studies are seemingly meaningful, since the prevalence of sleep disturbances increases with age [69], and it is higher in patients with dementia [70,71] and TBI, the prevalence rate being as great as 50%, which is much higher than that of the normal population [72,73]. Our findings are consistent with the observations of Kräuchi et al. [74], who reported the distal-to-proximal skin temperature gradient (DPG) during the 1.5 h period prior to lights-off for bedtime is the strongest predictor of SOL. It is also consistent with the proposal by the Van Someren group [4,13] it is the heat-loss dissipation induced by PBH-enhanced skin blood flow with consequent increase of skin temperature that in large part fosters sleep propensity as measured by shortened SOL.

DPG, an indicator of distal blood flow and indirect measure of distal heat loss [12], is elevated by PBH_{WB} [10,38,63]. Thus, it is not surprising PBH_{WB} treatment of proper temperature when applied at this optimal circadian time, 1–2 h before bedtime, is associated with improvement in SOL. When applied too early, 2 h or more before bedtime, it may induce feelings of sleepiness but it does not significantly shorten SOL. This finding is illustrated by the work of Horne and Reid [61], who applied baths of two different water temperatures (41 °C and 35.5 °C) 5 h or more prior to bedtime. Significant increase in before-bedtime tiredness was observed only after the heated bath (41 °C), although without significant shortening of SOL by this or the cooler 35.5 °C bath when applied so long before intended nighttime sleep. Overall, these results are in line with the observation that warm feet are associated with short SOL [4,12]. Nonetheless, it is noteworthy most studies that relied on subjective ratings reported improved sleep quality independent of the time before bedtime when PBH_{WB} was applied and whether or not objective sleep parameters when also measured were improved [54,55,58–60,65,67,68]. The greater subjective satisfaction of sleep associated with PBH_{WB} interventions might be indicative of a relaxation, in addition to physiological, effect. For example, a questionnaire survey by Goto et al. [32] of 2779 respondents found hot bath treatment associated with attenuated self-perceived stress.

The studies of Kim et al. [75] and Seo and Sohng [76] concerning the effect of a footbath on different sleep parameters were excluded from our systematic review and meta-analysis because they failed to satisfy inclusion criteria, i.e., they incorporated, in combination with PBH_{WB}, the wearing of socks as an additional treatment. Nonetheless, the findings of these studies are relevant because they illustrate the role of influential variables on outcomes. Kim et al. [75], who utilized a footbath intervention 1.5 h before bedtime, failed to detect significant attenuation of SOL. A possible explanation could be the donning of socks by subjects immediately following footbath heating. Hands and feet are the body's principal sites of controlled heat exchange [77] due to the high density of capillary bed and arteriovenous anastomoses (AVAs) of the palms and soles [78]. AVAs are vascular shunts that connect arterioles to venules; when vasodilated their diameter can enlarge 10-fold more than that of capillaries to shunt a very large volume of blood from core to peripheral skin sites [78]. The increased distal blood flow enhances transfer of heat to the hands and feet where it can be efficiently dissipated, resulting in rapid core body temperature (CBT) decline. PBH_{WB} accomplished by footbath induces AVA vasodilation that under normal conditions naturally improves heat loss; however, socks, especially ones of dense fabric, can act as an insulating layer at the foot-air boundary and obstruct body heat dissipation. Thus, the donning of socks immediately following warm foot bathing in the Kim et al. study [75] could explain lack of improvement in SOL. Seo and Sohng [76] also used socks to maintain the warmth of the feet of their subjects following warm footbath intervention. However, unlike the study of Kim et al. [64], Seo and Sohng [76] observed significant reduction in SOL relative to baseline nights. It is unclear whether the baseline nights of this latter investigation also included wearing of socks. The differences in outcomes between the Kim et al. [75] and Seo and Sohng [76] trials suggest involvement of socks of varying insulating quality or undisclosed methodological or participant-dependent factors.

Morris et al. [79] observed phase delay of the circadian CBT rhythm of insomniacs compared to normal sleepers, resulting in higher CBT at bedtime and later occurrence of CBT nadir during sleep than expected. On the other hand, Monroe [80] found poor sleepers have a lower CBT compared to good sleepers. These observations suggest the absolute CBT level at bedtime is the variable most strongly associated with SOL duration. However, the results of several other studies indicate extent of CBT attenuation (ΔCBT), rather than actual CBT, achieved before bedtime by a warm bath or shower is most strongly associated with shortening of SOL. Mishima et al. [64], who used a warm bath to the mid-thorax level to increase the CBT to a higher level before bedtime on treatment than baseline nights, reported shorter SOL on treatment than baseline nights. This implies as a hypothesis amount of the PBH_{WB}-induced lowering of CBT before bedtime is a potential mechanism of the significant shortening of SOL we found through our statistical analysis of previously published data. The findings of Campbell and Broughton [81] are consistent with this hypothesis; they demonstrated association between sleep initiation and ΔCBT decline. Jordan et al. [62] scheduled PBH_{WB} 5.75 h before lights-off for sleep. CBT was significantly higher on treatment nights, even after sleep onset, compared to baseline nights; nonetheless, the SOL was unchanged. The graphs shown in this publication indicate the decline in CBT consequent to PBH_{WB} occurred primarily during the 2 h after its application, i.e., almost 4 h before bedtime. These findings are consistent with the observation that poor compared to good sleepers exhibit a smaller ΔCBT just before the commencement of sleep [80,82] and also the hypothesis ΔCBT and its rate of change rather than the actual CBT achieved by PBH_{WB} is responsible for the shortening of SOL. This hypothesis is consistent with the one proposed earlier by the Van Someren group [4,13] that heat-loss activation is a causal mechanism of sleep propensity and maintenance. In this regard, Gillberg and Akerstedt [83] reported a favorable effect of PBH_{WB} on SWS in association with enhanced decline of CBT around the time of sleep onset, and Sewitch [84] and Horne and Staff [85] reported favorable effect of PBH_{WB} on increased time spent in Stage four sleep in association with substantial drop in CBT.

Some investigators cite the importance of the magnitude of the heat load conveyed by PBH_{WB} treatment, which is a function of both its duration and temperature, in affecting sleep. Liao et al. [86], who investigated the optimal temperature for footbath interventions, reported those of 40° or 41 °C significantly increased DPG, even within 10 min of application, but that only the higher temperature 41 °C footbath increased CBT. Horne and Shackell [87] applied 0.5 and 1.5 h warm bath interventions to the mid-thorax level between 20:00 and 22:00 h before bedtime at 23:45 h, finding the longer 1.5 h-duration, i.e., higher heat load, treatment relative to the baseline condition not only increased SOL but disturbed sleep with multiple awakenings. In contrast, the shorter 0.5 h duration warm bath, i.e., lower heat load, increased the amount of SWS. The findings of this investigation emphasize the potential importance of the total heat load delivered by the PBH_{WB} in relation to sleep outcomes. They also highlight the need for further investigation to determine the optimal duration and temperature of such interventions.

This review is based on a thorough search of the most relevant databases for pertinent investigations without filter for publication date or language. A total of 17 publications met inclusion and exclusion criteria; nonetheless, we are obligated to acknowledge deficiencies in their methods and conduct based on JBI checklists established for quasi-experimental, randomized control, and prospective cohort studies [40,41]. Common deficiencies are incomplete or inappropriate statistical methods – absence of power analysis, effect size, and/or other calculations, lack of control group, insufficient information concerning reliability of measurements, and no or insufficient follow-up assessment. Moreover, the measured sleep parameters of TST, SE, WASO, SOL are interdependent such that changes in one can cause change in others. Moreover, there were only two studies entailing objective measurement of SOL in which PBH_{WB} commenced and ended 1–2 h before bedtime. Furthermore, the sample size of the diverse investigations varied greatly with only ~35% of them involving more than 20 participants. Additionally, the subjects of many studies were quite young, even though PBH_{WB} methods are more likely to be recommended to elderly insomniacs than middle-age and young adults. The average age of participants of five of the 17 studies (~30%) was less than 40 y, and although ~35% of the reviewed investigations entailed individuals older than 60–65 y of age, only three pertained specifically to elderly insomniacs. Finally, there was marked difference among the 17 studies as to the means of PBH_{WB} exposure, water temperature, timing, and duration. In spite of the many differences between the reviewed investigations, the collective findings implicate the potential worthiness of PBH_{WB} treatment of optimal temperature and timing as a simple and low-cost nonpharmacological means of managing sleep-onset insomnia and improving overall sleep quality. Nonetheless, long-term, large sample-sized trials, particularly entailing elderly persons and chronic disease patients who experience difficulty falling asleep and who may be differentially responsive to PBH_{WB} strategies [4], are recommended to properly assess their merit and limitations.

Conclusion

Our systematic review of the literature supports the conclusion nightly warm showering, foot bathing, or full body bathing scheduled 1–2 h before bedtime for a duration as short as 10 min can improve sleep, especially shortening of SOL, most likely by enhancing decrement in CBT before bedtime. Our conclusion regarding the proper scheduling of PBH_{WB} before bedtime, however, is based on the findings of only two studies entailing in total 36 subjects, thereby highlighting the need for more extensive investigation. The investigations reviewed herein reconfirm association between PBH_{WB}-induced warming of the palms and soles and shortening of SOL. Additionally, a small number of PBH_{WB} trials indicates achieved ΔCBT around bedtime is more important than achieved absolute CBT in determining the beneficial effect on SOL and perhaps other sleep parameters, such as SWS and SE. Future research is required to confirm the optimal circadian stage/interval of time before bedtime; duration, temperature, means (footbath or other) of PBH_{WB} treatment. Future investigation is also required to assess the impact upon PBH_{WB} outcomes exerted by influential factors and conditions that may affect outcomes, such as after-intervention donning of socks and attributes of sleep ware. Study is also encouraged to determine the types of sleep complaints as well as medical and demographic characteristics of those most likely to benefit from PBH_{WB} intervention.

Practice Points

- Warming of hands and feet achieved by warm shower or foot or body baths for a duration as short as 10 min scheduled 1–2 h before bedtime is associated with shortened sleep onset latency and increased sleep efficiency.
- Warm shower or foot or body baths can enhance subjective sleep quality, perhaps not only through shortened sleep onset latency and increased sleep efficiency, but through increased slow wave sleep and improvement of other sleep parameters, such as wake after sleep onset and total sleep time.
- Passive body heating effects on sleep readiness and sleep onset latency seem to be most strongly associated with achieved extent of decline in core body temperature rather than achieved level of core body temperature.

Research Agenda

- Clarify physiological mechanisms – level, amount, and rate of change of core body temperature – of improvements in sleep parameters and quality attributed to water-based passive body heating.
- Confirm the optimal timing, duration, temperature, and total heat load of water-based passive body heating interventions.
- Determine the effect of sleep ware and socks on the therapeutic impact of water-based passive body heating interventions.
- Determine the spectrum of sleep disorders for which water-based passive body heating is beneficial and factors of individuals that affect outcomes.
- Conduct long-term, large sample trials entailing elderly and chronic-diseased individuals with complaint of sleep dissatisfaction.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smrv.2019.04.008.

References

[1] Feinstein EL. Bathing in the Hebrew Bible. 2018. https://www.bibleodyssey.org/en/people/related-articles/bathing-in-the-hebrew-bible (accessed August 20, 2018).
[2] van Tubergen A, van der Linden S. A brief history of spa therapy. Ann Rheum Dis 2002;61:273–5.
[3] Gunn JC. Gunn's domestic medicine. Philadelphia: G. V. Raymond; 1840.
*[4] Raymann RJEM, Swaab DF, Van Someren EJW. Skin temperature and sleep-onset latency: changes with age and insomnia. Physiol Behav 2007;90: 257–66. https://doi.org/10.1016/j.physbeh.2006.09.008.
[5] Huffman C. "Alcmaeon", The Stanford Encyclopedia of Philosophy (Spring 2017). 2017. https://plato.stanford.edu/archives/spr2017/entries/alcmaeon/.
[6] Finkbeiner AK. Getting through the sleep gate. Sciences 1998;38:14–8. https://doi.org/10.1002/j.2326-1951.1998.tb03657.x.
[7] Jürgensen T. Die Körperwärme des gesunden Menschen: Studien. FCW Vogel; 1873.
[8] Davy J. On the temperature of man. Philos Trans R Soc Lond 1845;135: 319–33. https://doi.org/10.1098/rstl.1845.0014.
[9] Dalton JC. Treatise on human physiology. Philadelphia: Henry C. Lea; 1875.
*[10] Raymann RJEM, Swaab DF, Van Someran EJW. Cutaneous warming promotes sleep onset. Am J Physiol Integr Comp Physiol 2005;288:R1589–97. https://doi.org/10.1152/ajpregu.00492.2004.
*[11] Van Someren EJW. Mechanisms and functions of coupling between sleep and temperature rhythms. Prog Brain Res 2006;153:309–24. https://doi.org/10.1016/S0079-6123(06)53018-3.
*[12] Kräuchi K, Cajochen C, Werth E, Wirz-justice A. Warm feet promote the rapid onset of sleep. Nature 1999;401:36.
*[13] Van Someren EJW. More than a marker: interaction between the circadian regulation of temperature and sleep, age-related changes, and treatment possibilities. Chronobiol Int 2000;17:313–54.
[14] Hofman MA, Swaab DF. Living by the clock: the circadian pacemaker in older people. Ageing Res Rev 2006;5:33–51.
*[15] Lack LC, Gradisar M, Van Someren EJW, Wright HR, Lushington K. The relationship between insomnia and body temperatures. Sleep Med Rev 2008;12: 307–17. https://doi.org/10.1016/j.smrv.2008.02.003.
[16] Vitiello MV. Sleep disorders and aging: understanding the causes. J Gerontol A Biol Sci Med Sci 1997;52:M189–91.
[17] McCrae CS. Late-life comorbid insomnia: diagnosis and treatment. Am J Manag Care 2009;15:S14–23.

* The most important references are denoted by an asterisk.

[18] Fronczek R, Overeem S, Lammers GJ, van Dijk JG, Van Someren EJW. Altered skin-temperature regulation in narcolepsy relates to sleep propensity. Sleep 2006;29:1444–9. https://doi.org/10.1093/sleep/29.11.1444.
[19] Maness DL, Khan M. Nonpharmacologic management of chronic insomnia. Am Fam Physician 2015;92:1058–64.
[20] Ohayon MM, Lemoine P. Sleep and insomnia markers in the general population. Encephale 2004;30:135–40.
[21] Ohayon MM. Nocturnal awakenings and comorbid disorders in the American general population. J Psychiatr Res 2008;43:48–54.
[22] Gislason T, Reynisdottir H, Kristbjarnarson H, Benediktsdottir B. Sleep habits and sleep disturbances among the elderly—an epidemiological survey. J Intern Med 1993;234:31–9.
[23] Wade A, Zisapel N, Lemoine P. Prolonged-release melatonin for the treatment of insomnia: targeting quality of sleep and morning alertness. Aging Health 2008;4:11–21. https://doi.org/10.2217/1745509X.4.1.11.
[24] Harding K, Feldman M. Sleep disorders and sleep deprivation: an unmet public health problem. J Am Acad Child Adolesc Psychiatry 2008;47:473–4. https://doi.org/10.1097/01.CHI.0000270812.55636.3b.
[25] Reeder CE, Franklin M, Bramley TJ. Current landscape of insomnia in managed care. Am J Manag Care 2007;13:S112–6.
[26] Liao WC. Effects of passive body heating on body temperature and sleep regulation in the elderly: a systematic review (Structured abstract). Int J Nurs Stud 2002;39:803–10.
[27] Heffernan C. Good night, sleep tight. Vibrant Life 2015;31:20–1.
[28] Winter G. Daily foot bathing increases sleep quality. Pract Nurs 2016;27:296.
[29] Aritake-Okada S, Kaneita Y, Uchiyama M, Mishima K, Ohida T. Non-pharmacological self-management of sleep among the Japanese general population. J Clin Sleep Med 2009;5:464–9.
[30] Ojima T, Hayasaka S, Murata C, Nakade M, Nakamura M, Nakamura H, et al. 13-4 Regular bathing and sleep quality among older Japanese: large scale JAGES project. J Jpn Soc Balneol Climatol Phys Med 2014;77:522–3.
[31] Hayasaka S, Shibata Y, Goto Y, Noda T, Ojima T. Bathing in a bathtub and health status: a cross-sectional study. Complement Ther Clin Pract 2010;16:219–21. https://doi.org/10.1016/j.ctcp.2010.05.002.
[32] Goto Y, Hayasaka S, Nakamura Y. Bathing in hot water, bathing in Japanese style hot spring and drinking green tea may contribute to the good health status of Japanese. J Jpn Soc Balneol Climatol Phys Med 2012;75:256–67.
[33] Camilleri S, Barrett C. The impact of nursing practice on sleep in the older person. Aust Nurs J 2000;7:34.
[34] Yu L, Su B, Wang X, Li M, Ma W. Experimental study on skin temperature and thermal response of the foot-bather. J Therm Anal Calorim 2016;123:2507–16. https://doi.org/10.1007/s10973-015-5063-5.
*[35] Raymann RJW, Swaab DF, Van Someren EJW. Skin deep: enhanced sleep depth by cutaneous temperature manipulation. Brain 2008;131:500–13. https://doi.org/10.1093/brain/awm315.
[36] Deguchi A, Nakamura S, Yoneyama S, Hamaguchi H, Kawamura Y, Horio S, et al. Improving symptoms of senile dementia by a night-time spa bathing. Arch Gerontol Geriatr 1999;29:267–73.
[37] Dowdell WT, Javaheri S. Lack of effect of external warming on sleep architecture in sleep apnea/hypopnea syndrome. Am Rev Respir Dis 1992;145:137–40. https://doi.org/10.1164/ajrccm/145.1.137.
[38] Liao WC, Wang L, Kuo C-PP, Lo C, Chiu M-JJ, Ting H. Effect of a warm footbath before bedtime on body temperature and sleep in older adults with good and poor sleep: an experimental crossover trial. Int J Nurs Stud 2013;50:1607–16. https://doi.org/10.1016/j.ijnurstu.2013.04.006.
[39] Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred reporting items for systematic reviews and meta-analyses : the PRISMA statement. PLoS Med 2009;6:e1000097. https://doi.org/10.1371/journal.pmed.1000097.
[40] Tufanaru C, Munn Z, Aromataris E, Campbell J, Hopp L. Chapter 3: systematic reviews of effectiveness. In: Aromataris E, Munn Z, editors. Joanna Briggs Institute reviewer's manual. The Joanna Briggs Institute; 2017. Available from: https://reviewersmanual.joannabriggs.org/.
[41] Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R, et al. Chapter 7: systematic reviews of etiology and risk. In: Aromataris E, Munn Z, editors. Joanna Briggs Institute reviewer's manual. The Joanna Briggs Institute; 2017. Available from: https://reviewersmanual.joannabriggs.org/.
[42] Coe R. It's the effect size, stupid: what effect size is and why it is important. Annu Conf Br Educ Res Assoc 2002. Available from: http://www.leeds.ac.uk/educol/documents/00002182.htm.
[43] Headrick TC. Statistical simulation: power method polynomials and other transformations. Chapman and Hall/CRC; 2009.
[44] Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. Introduction to meta-analysis. Chichester, UK: John Wiley & Sons, Ltd; 2009. https://doi.org/10.1002/9780470743386.
[45] Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. 1988.
[46] Borenstein M, Higgins JPT. Meta-analysis and subgroups. Prev Sci 2013;14:134–43. https://doi.org/10.1007/s11121-013-0377-7.
[47] Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions version 5.1.0 [updated March 2011]. The Cochrane Collaboration; 2011. Available from: www.handbook.cochrane.org.
[48] Thompson SG, Higgins JPT. How should meta-regression analyses be undertaken and interpreted? Stat Med 2002 Jun 15;21(11):1559–73.
[49] Bown MJ, Sutton AJ. Quality control in systematic reviews and meta-analyses. Eur J Vasc Endovasc Surg 2010;40:669–77. https://doi.org/10.1016/j.ejvs.2010.07.011.
[50] Rao G, Lopez-Jimenez F, Boyd J, D'Amico F, Durant NH, Hlatky MA, et al. Methodological standards for meta-analyses and qualitative systematic reviews of cardiac prevention and treatment studies a scientific statement from the American Heart Association. Circulation 2017;136:e172–94. https://doi.org/10.1161/CIR.0000000000000523.
[51] Higgins JPT. Measuring inconsistency in meta-analyses. BMJ 2003;327:557–60. https://doi.org/10.1136/bmj.327.7414.557.
[52] Richardson M, Garner P, Donegan S. Interpretation of subgroup analyses in systematic reviews: a tutorial. Clin Epidemiol Glob Health 2018. https://doi.org/10.1016/j.cegh.2018.05.005.
[53] Macaskill P, Walter SD, Irwig L. A comparison of methods to detect publication bias in meta-analysis. Stat Med 2001;20:641–54. https://doi.org/10.1002/sim.698.
[54] Namba S, Shimoyama I, Kiguchi T, Ujike Y. Effects of foot baths on sleep in ICU patients. Chiba Med J 2012;88:59–64.
[55] Sung EJ, Tochihara Y. Effects of bathing and hot footbath on sleep in winter. J Physiol Anthropol Appl Hum Sci 2000;19:21–7. https://doi.org/10.2114/jpa.19.21.
[56] Whitworth-Turner C, Di Michele R, Muir I, Gregson W, Drust B. A shower before bedtime may improve the sleep onset latency of youth soccer players. Eur J Sport Sci 2017;17:1119–28. https://doi.org/10.1080/17461391.2017.1346147.
[57] Chiu HY, Lin EY, Chiu HT, Chen PY. A feasibility randomized controlled crossover trial of home-based warm footbath to improve sleep in the chronic phase of traumatic brain injury. J Neurosci Nurs 2017;49:380–5. https://doi.org/10.1097/JNN.0000000000000325.
[58] Dorsey CM, Lukas SE, Teicher MH, Harper D, Winkelman JW, Cunningham SL, et al. Effects of passive body heating on the sleep of older female insomniacs. J Geriatr Psychiatry Neurol 1996;9:83–90. https://doi.org/10.1177/089198879600900203.
[59] Dorsey CM, Teicher MH, Cohen-Zion M, Stefanovic L, Satlin A, Tartarini W, et al. Core body temperature and sleep of older female insomniacs before and after passive body heating. Sleep 1999;22:891–8.
[60] Furushima C, Inoue N, Kodama Y, Wakeshima R. Footbathing as an effective method to ameliorate inpatient sleeplessness. J Jpn Acad Nurs Sci 2009;29:79–87.
[61] Horne JA, Reid AJ. Night-time sleep EEG changes following body heating in a warm bath. Electroencephalogr Clin Neurophysiol 1985;60:154–7. https://doi.org/10.1016/0013-4694(85)90022-7.
[62] Jordan J, Montgomery I, Trinder J. The effect of afternoon body heating on body temperature and slow wave sleep. Psychophysiology 1990;27:560–6. https://doi.org/10.1111/j.1469-8986.1990.tb01976.x.
[63] Liao WC, Chiu MJ, Landis CA. A warm footbath before bedtime and sleep in older Taiwanese with sleep disturbance. Res Nurs Health 2008;31:514–28. https://doi.org/10.1002/nur.20283.
[64] Mishima Y, Hozumi S, Shimizu T, Hishikawa Y, Mishima K. Passive body heating ameliorates sleep disturbances in patients with vascular dementia without circadian phase-shifting. Am J Geriatr Psychiatry 2005;13:369–76. https://doi.org/10.1176/appi.ajgp.13.5.369.
[65] Rahmani A, Naseri M, Salaree MM, Nehrir B. Comparing the effect of foot reflexology massage, foot bath and their combination on quality of sleep in patients with acute coronary syndrome. J Caring Sci 2016;5:299–306. https://doi.org/10.15171/jcs.2016.031.
[66] Cherian S. The effect of footbath on sleep onset latency and relaxation among patients with cancer. Int J Nurs Educ 2012;4:188–92.
[67] Seyyedrasooli A, Valizadeh L, Zamanzadeh V, Nasiri K, Kalantri H. The effect of footbath on sleep quality of the elderly: a blinded randomized clinical trial. J Caring Sci 2013;2:305–11. https://doi.org/10.5681/jcs.2013.036.
[68] Yang HL, Chen XP, Lee KC, Fang FF, Chao YF. The effects of warm-water footbath on relieving fatigue and insomnia of the gynecologic cancer patients on chemotherapy. Cancer Nurs 2010;33:454–60. https://doi.org/10.1097/NCC.0b013e3181d761c1.
[69] Crowley K. Sleep and sleep disorders in older adults. Neuropsychol Rev 2011:41–53. https://doi.org/10.1007/s11065-010-9154-6.
[70] Zhou QP, Jung L, Richards KC. The management of sleep and circadian disturbance in patients with dementia. Curr Neurol Neurosci Rep 2012;12:193–204. https://doi.org/10.1007/s11910-012-0249-8.
[71] Rose KM, Fagin CM, Lorenz R. Sleep disturbances in dementia: what they are and what to do. J Gerontol Nurs 2010;36:9–14. https://doi.org/10.3928/00989134-20100330-05.
[72] Mathias JL, Alvaro PK. Prevalence of sleep disturbances, disorders, and problems following traumatic brain injury: a meta-analysis. Sleep Med 2012;13:898–905. https://doi.org/10.1016/j.sleep.2012.04.006.
[73] Grima N, Ponsford J, Rajaratnam SM, Mansfield D, Pase MP. Sleep disturbances in traumatic brain injury: a meta-analysis. J Clin Sleep Med 2016;12:419–28. https://doi.org/10.5664/jcsm.5598.
*[74] Kräuchi K, Cajochen C, Werth E, Wirz-Justice A. Functional link between distal vasodilation and sleep-onset latency? Am J Physiol Regul Integr Comp Physiol 2000;278:R741–8. https://doi.org/10.1111/j.1365-2869.2004.00401.x.
[75] Kim HJ, Lee Y, Sohng KY. The effects of footbath on sleep among the older adults in nursing home: a quasi-experimental study. Complement Ther Med 2016;26:40–6. https://doi.org/10.1016/j.ctim.2016.02.005.

[76] Seo H, Sohng K. The effect of footbaths on sleep and fatigue in older Korean adults. J Korean Acad Fundam Nurs 2011;18:488–96.
[77] Romanovsky AA. Skin temperature: its role in thermoregulation. Acta Physiol 2014;210:498–507. https://doi.org/10.1111/apha.12231.
*[78] Diller KR. Therapeutic recruitment of thermoregulation in humans by selective thermal stimulation along the spine. Adv Heat Transf 2015;47: 341–96. https://doi.org/10.1016/bs.aiht.2015.08.002.
[79] Morris M, Lack L, Dawson D. Sleep-onset insomniacs have delayed temperature rhythms, vol. 13. Raven Press, Ltd; 1990.
[80] Monroe LJ. Psychological and physiological differences between good and poor sleepers. J Abnorm Psychol 1967;72:255–64. https://doi.org/10.1037/h0024563.
*[81] Campbell SS, Broughton RJ. Rapid decline in body temperature before sleep: fluffing the physiological pillow? Chronobiol Int 1994;11:126–31. https://doi.org/10.3109/07420529409055899.
[82] Lack L, Balfour R, Kalucy R. The circadian rhythm of body temperature in poor sleepers. Sleep Res 1985;14:301.
[83] Gillberg M, Akerstedt T. Body temperature and sleep at different times of day. Sleep 1982;5:378–88.
[84] Sewitch DE, Kittrell EM, Kupfer DJ, Reynolds CF. Body temperature and sleep architecture in response to a mild cold stress in women. Physiol Behav 1986;36:951–7.
[85] Horne JA, Staff LH. Exercise and sleep: body-heating effects. Sleep 1983;6: 36–46.
[86] Liao WC, Landis CA, Lentz MJ, Chiu MJ. Effect of foot bathing on distal-proximal skin temperature gradient in elders. Int J Nurs Stud 2005;42: 717–22. https://doi.org/10.1016/j.ijnurstu.2004.11.011.
[87] Horne JA, Shackell BS. Slow wave sleep elevations after body heating: proximity to sleep and effects of aspirin. Sleep 1987;10:383–92.