



The experienced temperature sensitivity and regulation survey

Eus J. W. Van Someren, Kim Dekker, Bart H. W. Te Lindert, Jeroen S. Benjamins, Sarah Moens, Filippo Migliorati, Emmeke Aarts & Sophie van der Sluis

To cite this article: Eus J. W. Van Someren, Kim Dekker, Bart H. W. Te Lindert, Jeroen S. Benjamins, Sarah Moens, Filippo Migliorati, Emmeke Aarts & Sophie van der Sluis (2016) The experienced temperature sensitivity and regulation survey, *Temperature*, 3:1, 59-76, DOI: [10.1080/23328940.2015.1130519](https://doi.org/10.1080/23328940.2015.1130519)

To link to this article: <http://dx.doi.org/10.1080/23328940.2015.1130519>



© 2016 The Author(s). Published with license by Taylor & Francis Group, LLC
© 2016 Eus JW Van Someren, Kim Dekker, Bart HW Te Lindert, Jeroen S Benjamins, Sarah Moens, Filippo Migliorati, Emmeke Aarts and Sophie van der Sluis
Accepted author version posted online: 18 Dec 2015.



[View supplementary material](#)



Accepted author version posted online: 18 Dec 2015.



[Submit your article to this journal](#)



Article views: 103



[View related articles](#)



[View Crossmark data](#)



METHOD ARTICLE

The experienced temperature sensitivity and regulation survey

Eus J. W. Van Someren^{a,b}, Kim Dekker^a, Bart H. W. Te Lindert^a, Jeroen S. Benjamins^{a,c}, Sarah Moens^a, Filippo Migliorati^a, Emmeke Aarts^{d,e}, and Sophie van der Sluis^f

^aDepartment of Sleep and Cognition, Netherlands Institute for Neuroscience, an institute of the Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands; ^bDepartments of Integrative Neurophysiology and Medical Psychology, Center for Neurogenomics and Cognitive Research, Neuroscience Campus Amsterdam, VU University and Medical Center, Amsterdam, the Netherlands; ^cDepartment of Social, Health and Organizational Psychology, Department of Experimental Psychology, Utrecht University, Utrecht, The Netherlands; ^dDepartment of Functional Genomics, Center for Neurogenomics and Cognitive Research (CNCR), VU University Amsterdam, Amsterdam, the Netherlands; ^eDepartment of Computational Molecular Biology, Max Planck Institute for Molecular Genetics, Berlin, Germany; ^fDepartment of Clinical Genetics, Section Complex Trait Genetics, VU Medical Center, Amsterdam, the Netherlands

ABSTRACT

Individuals differ in thermosensitivity, thermoregulation, and zones of thermoneutrality and thermal comfort. Whereas temperature sensing and -effectuating processes occur in part unconsciously and autonomic, awareness of temperature and thermal preferences can affect thermoregulatory behavior as well. Quantification of trait-like individual differences of thermal preferences and experienced temperature sensitivity and regulation is therefore relevant to obtain a complete understanding of human thermophysiology. Whereas several scales have been developed to assess instantaneous appreciation of heat and cold exposure, a comprehensive scale dedicated to assess subjectively experienced autonomic or behavioral thermoregulatory activity has been lacking so far. We constructed a survey that specifically approaches these domains from a trait-like perspective, sampled 240 volunteers across a wide age range, and analyzed the emergent component structure. Participants were asked to report their thermal experiences, captured in 102 questions, on a 7-point bi-directional Likert scale. In a second set of 32 questions, participants were asked to indicate the relative strength of experiences across different body locations. Principal component analyses extracted 21 meaningful dimensions, which were sensitive to sex-differences and age-related changes. The questions were also assessed in a matched sample of 240 people with probable insomnia to evaluate the sensitivity of these dimensions to detect group differences in a case-control design. The dimensions showed marked mean differences between cases and controls. The survey thus has discriminatory value. It can freely be used by anyone interested in studying individual or group differences in thermosensitivity and thermoregulation.

ARTICLE HISTORY

Received 6 October 2015
Revised 20 November 2015
Accepted 24 November 2015

KEYWORDS

survey; individual differences; temperature; thermosensitivity; thermoregulation; sex differences; aging; insomnia

Introduction

Human thermoregulation involves a complex system of thermosensors and thermoeffectors.¹ Individual differences in thermosensitivity, thermoregulation, and zones of thermoneutrality and thermal comfort remain an important topic.^{2–4} Differences may occur in the capability to sense temperature, in thermoregulatory capacities, or in the tolerance range. Temperature sensing and effectuating processes occur in part unconsciously and autonomic. However, awareness

of temperature as well as thermal preferences can affect behavioral thermoregulation. It could thus be important to quantify trait-like individual differences, for example related to sex, age or disorders, in how people experience their thermal environment and their own thermosensitivity and thermoregulatory responses.

Various scales exist to assess thermal sensation, comfort, and preference based on the ISO 7730 standard. One type of assessment used 7 to 11-point Likert

CONTACT Eus J. W. Van Someren ✉ e.van.someren@nin.knaw.nl 📍 Netherlands Institute for Neuroscience (NIN), Meibergdreef 47, 1105 BA, Amsterdam
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ktmp.

📎 Supplemental data for this article can be accessed on the publisher's website.

© 2016 Eus JW Van Someren, Kim Dekker, Bart HW Te Lindert, Jeroen S Benjamins, Sarah Moens, Filippo Migliorati, Emmeke Aarts, and Sophie van der Sluis. Published with license by Taylor and Francis.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited. The moral rights of the named author(s) have been asserted.

scales ranging from extremely hot to extremely cold.⁵⁻⁷ Another type of momentary temperature sensation assessment used visual-analog scales.^{8,9} The scales typically address thermal sensation, comfort, or preference, but not subjectively experienced autonomic or behavioral thermoregulatory activity. For dedicated research questions, ad hoc questions about habitual thermosensitivity have been implemented. For example, Gompfer et al.¹⁰ aimed to quantify vascular dysregulation using Likert-scale ratings on two questions about habitually experiencing cold hands and feet. However, we are not aware of scales designed to comprehensively assess stable trait-like individual differences with respect to the domains of thermal sensation, temperature preference, and subjectively experienced autonomic or behavioral thermoregulatory activity. We constructed a survey that approaches these domains from a trait-like perspective. In the present study, we examine the survey's component structure using Principal Component Analysis, and provide examples of the survey's sensitivity to pick up subjective counterparts of previously documented sex differences and age-related changes in objective thermosensitivity and thermoregulation, as well as the survey's sensitivity to pick up such subjective differences between people without sleep complaints and those suffering from probable insomnia.

The study of sex differences in the physiology of thermoregulation has a long history and interpretations continue to be a topic of discussion.¹¹⁻¹⁴ Estrogens have clear effects on thermoregulation, and in humans the 24-hour profile of estradiol peaks during the part of the night when core body temperature is at its lowest.¹⁵ *In vitro* studies showed that estradiol may interact with thermoregulation at the most fundamental level; it immediately affects the firing rate of a large proportion of the thermosensitive neurons in the pre-optic area,¹⁶ the highest in the hierarchy of brain structures involved in thermoregulation. These findings give reason to evaluate whether our new survey is sensitive to sex differences in subjectively experienced temperature sensitivity and regulation that complement objective observations of sex differences in objective thermosensitivity and thermoregulation.

As is the case for studies on sex differences, studies on the effects of aging on the physiology of thermoregulation continue to refine and specify earlier findings.¹⁷⁻²⁰ Age-related decreases have been suggested to occur at several levels of the thermoregulatory system, including thermosensitivity, thermogenesis and

conservation, heat loss, and central regulation. However, which part of these changes result from the aging process *per se* remains an issue of ongoing discussion. Several changes may be explained by other factors that change with aging, notably a decreased level of fitness and physical activity. Among the most robust findings is that aging attenuates the amplitude of the 24-hour rhythm in core body temperature. This finding is paralleled with lower 24-hour rhythm amplitudes in many other physiological rhythms, likely all involving functional changes in the suprachiasmatic nucleus, the central biological clock of the brain.²¹ It therefore seems of interest to evaluate whether these objective observations are complemented by age-related changes in subjectively experienced temperature sensitivity and regulation across daytime and nighttime.

As a final example of the use of the survey, we explore disorder-related deviations in a case-control design. Specifically, we investigate experienced temperature sensitivity and regulation in people suffering from probable insomnia disorder. Differences in thermoregulation between people who do or do not suffer from probable insomnia can be expected based on numerous studies showing a strong interaction of sleep regulation with temperature sensitivity and temperature regulation. Firstly, there is strong support for the 24-hour synchronization of sleep with the core body temperature rhythm. Sleep onset is facilitated during the decline of core body temperature, and indeed delayed 24-hour profiles of core body temperature and other rhythms are associated with sleep onset problems.^{22,23} Sleep terminates on the rising curve of 24-hour temperature cycle, and more likely so in people with a relatively low gray matter volume in a part of the cerebral cortex at the border of the anterior insula and orbitofrontal cortex,^{24,25} key areas in the experienced intensity of thermal stimuli.²⁶ Secondly, the key feature of insomnia is a generalized hyperarousal, which may not only show from increased body temperature but also from factors affecting thermoregulation including increased resting metabolic rate, cortisol secretion and sympathetic tone.^{27,28} Recent structural and functional imaging studies have suggested possible brain mechanisms underlying the hyperaroused state.²⁹ Thirdly, daytime performance and nocturnal sleep as well as their associated electroencephalographic profiles, respond to natural fluctuations and induced small changes in skin temperature within the thermoneutral zone.^{30,31} Moreover, this association is altered both after experimentally disrupted sleep³² and in people suffering

from insomnia.^{33,34} Finally, people with insomnia have poor judgment of whether the temperature of the sleeping environment is comfortable,⁹ which may involve a relatively low gray matter volume in the orbitofrontal cortex,³⁵⁻³⁷ given its crucial role in hedonic evaluation including thermal comfort.^{38,39} Concertedly, these observations give reason to evaluate whether our new assessment instrument is sensitive enough to detect deviations in subjectively experienced temperature sensitivity and regulation in people suffering from probable insomnia disorder compared to those without sleep complaints.

Results

Questions generated

Questions were generated with the help of an expert panel consisting of researchers participating in ThermoNed, an open society with annual meetings since initiated in 2003 by Hein Daanen, Wouter Van Marken Lichtenbelt and Eus Van Someren, with the aim to facilitate exchange of expertise and cooperation among temperature researchers in the Netherlands. A total of 136 questions were generated. Question domains are described in more detail in the Materials and Methods section and all questions are listed in Appendix 1. In brief, questions covered one or more of the following features: (1) four inputs that impinge on the thermoregulatory system (heat, cold, physical activity, and stress); (2) six discernable perceivable thermosensitive and thermoregulatory readouts (preference, sensing deviation, subjective body temperature, autonomic response, behavioral response, and vigilance response - sleepiness or alertness); (3) three homeostatic drive categories (heat loss, heat preservation and vigilance - the drive towards either sleepiness or alertness); (4) five categories capturing the body location of thermal sensitivity or response (head, distal, proximal, internal or unspecified); (5) three categories specifying seasonal aspects (summer, winter, unspecified); and (6) three categories specifying the diurnal context (bed time, wake time, unspecified). In a first set of 102 questions, participants compare their thermal experiences to that of others on a 7-point bi-directional Likert scale ranging from much less (scored as -3) to much more (scored as +3) with a neutral middle rating of 'like everyone else' (scored as 0, see Methods and Appendix 1). In a second set of 32 questions, participants use a 7-point bi-directional Likert scale to indicate the relative strength of experiences across

different body locations ranging from much less (scored as -3) to much more (scored as +3) with a neutral middle rating of 'like anywhere else' (scored as 0, see Methods and Appendix 1). Additional questions concern the nocturnal and diurnal settings of the central heating thermostats at home during the summer and winter. Since answers to these last questions were available in only part of the participants, these questions were not included in further analyses.

Participant assessment

The survey including 136 questions was made available as an online tool for participants of the Netherlands Sleep Registry (NSR), described in more detail in the Methods section. The median duration required to complete the survey was 9.5 minutes. For the present analysis, data were selected from a larger sample to represent four groups of 120 participants each, representing equal numbers of males versus females, and people without sleep complaints vs. people with probable insomnia disorder, across the wide age range of 21.5 to 69.7 years of age. On average, participants without sleep complaints were 53.8 ± 12.0 years of age, not different from the age of participants with probable insomnia disorder (55.0 ± 11.0 years of age, $P = 0.23$). Participants selected on the absence of sleep complaints all scored below the cut-off scores of both the Pittsburgh Sleep Quality Index (PSQI, ≤ 5)⁴⁰ and the Insomnia Severity Index (ISI, < 10),⁴¹ with average (\pm standard deviation) values of 3.3 ± 1.4 and 2.6 ± 2.6 , respectively. Participants selected on probable insomnia disorder all scored above these cut-off scores, with average values of 10.6 ± 2.3 and 16.7 ± 4.3 , respectively. All groups were matched on age and the two groups with probable insomnia disorder moreover on PSQI and ISI. Details on assessment procedures and participants are provided in the Materials and Methods Section. Group characteristics are shown in the upper part of Table 1.

Dimension reduction

Principal components analysis (PCA) with Varimax-rotation was applied to reduce the high dimensionality of the data into maximally independent components without making a priori assumptions about associations between questions. PCA is an often-used statistical data reduction tool that determines clusters of items from a larger pool (here the two sets of 102 and 32 items, respectively) that participants tend to respond to in a similar way, suggesting that they assess

Table 1. Participant descriptives, Principal Component Analysis (PCA)-extracted components on the strength of thermal experiences compared to other people and on the relative strength of thermal experiences across body locations.

	No sleep complaint										Insomnia											
	#	%Var	r(PCA)	All			Male			Female			All			Male			Female			
				Mean	St.Dev.	P(l-C)	Mean	St.Dev.	P(l-C)	Mean	St.Dev.	P(l-C)	Mean	St.Dev.	P(l-C)	Mean	St.Dev.	P(l-C)				
Participant descriptives																						
Age				53.78	[12.01]		53.97	[11.88]		53.59	[12.19]		55.04	[11.01]		55.06	[11.02]		55.02	[11.04]		0.23
PSQI				3.25	[1.36]		3.28	[1.34]		3.23	[1.39]		10.65	[2.29]		10.47	[2.44]		10.83	[2.12]		0.00000
ISI				2.58	[2.60]		2.56	[2.70]		2.60	[2.50]		16.73	[4.30]		16.95	[4.29]		16.51	[4.31]		0.00000
Components on the strength of thermal experiences compared to other people																						
1 Heat-induced Warming	5	3.7	0.81	0.14	[1.04]		0.21	[1.04]		0.07	[1.03]	0.14	0.29	-0.14	0.04	0.24	[1.09]		0.20	[1.21]	0.08	0.41
2 Activity-induced Warming	5	4.3	0.87	0.35	[0.91]		0.37	[0.93]		0.34	[0.89]	0.04	0.78	-0.23	0.0004	0.36	[0.98]		0.16	[1.11]	0.09	0.31
3 Heat/Activity-induced Auton. Thermoreg.	4	2.7	0.71	0.22	[1.18]		0.25	[1.22]		0.18	[1.13]	0.06	0.64	-0.14	0.03	0.48	[1.08]		0.16	[1.20]	0.09	0.34
4 Heat-induced Behavioral Thermoregulation	6	4.4	0.86	0.34	[1.09]		0.34	[1.09]		0.33	[1.10]	0.00	0.99	-0.13	0.04	0.62	[1.19]		0.25	[1.29]	0.09	0.35
5 Cold/Inactivity-induced Cooling & Thermoreg.	16	11.8	0.89	-0.10	[1.11]		-0.35	[1.07]		0.16	[1.08]	0.47	0.0003	-0.02	0.75	0.01	[1.17]		0.48	[1.18]	0.30	0.001
6 Heat Perception	7	6.8	0.92	0.22	[1.03]		0.21	[1.06]		0.22	[1.01]	0.01	0.94	-0.15	0.02	0.44	[1.15]		0.44	[1.01]	0.21	0.02
7 Cold Perception	7	6.4	0.86	-0.08	[1.20]		-0.32	[1.16]		0.16	[1.20]	0.41	0.002	0.04	0.54	0.04	[1.27]		0.52	[1.29]	0.29	0.002
8 Warmth-seeking Behav./Pref. in Warm Env.	7	3.4	0.80	-0.51	[0.84]		-0.67	[0.88]		-0.36	[0.78]	0.38	0.003	-0.06	0.38	-0.65	[0.82]		-0.45	[0.96]	0.04	0.64
9 Warmth-seeking Behav./Pref. in Cold Env.	5	2.8	0.67	0.35	[0.99]		0.15	[0.99]		0.55	[0.95]	0.41	0.002	0.03	0.63	0.37	[1.11]		0.77	[1.15]	0.21	0.02
10 Stress-induced Warming	9	6.5	0.95	0.03	[0.71]		0.01	[0.74]		0.05	[0.68]	0.05	0.69	-0.17	0.007	0.13	[0.83]		0.02	[0.71]	0.13	0.17
11 Stress-induced Cooling	5	4.7	0.91	-0.19	[0.87]		-0.35	[0.96]		-0.03	[0.74]	0.38	0.004	-0.01	0.90	-0.24	[1.09]		0.11	[1.06]	0.13	0.17
12 Heat&Activity-induced Fatigue	4	4.6	0.91	0.13	[1.46]		0.24	[1.47]		0.02	[1.45]	0.15	0.24	-0.19	0.003	0.86	[1.62]		0.86	[1.65]	0.47	0.00000
13 Cold-induced Fatigue	4	3.1	0.79	-0.32	[0.92]		-0.43	[1.00]		-0.21	[0.82]	0.25	0.06	-0.04	0.53	-0.04	[1.08]		0.06	[1.08]	0.33	0.0004
14 Stress-induced Fatigue	3	2.5	0.83	-0.03	[0.80]		-0.04	[0.84]		-0.01	[0.77]	0.04	0.73	-0.11	0.08	0.33	[1.04]		0.38	[1.01]	0.41	0.00001
87 67.7 0.84																						
Components on the relative strength of thermal experiences across different body locations																						
15 Distal When Warm Day	3	10.2	0.87	0.21	[0.60]		0.16	[0.56]		0.26	[0.63]	0.17	0.18	-0.06	0.35	0.33	[0.80]		0.32	[0.78]	0.16	0.07
16 Distal When Warm Night	4	8.7	0.96	0.26	[0.66]		0.20	[0.69]		0.31	[0.62]	0.16	0.20	-0.01	0.87	0.40	[0.74]		0.35	[0.80]	0.17	0.06
17 Distal When Cold Night&Day	5	8.0	0.92	0.58	[0.83]		0.37	[0.75]		0.79	[0.85]	0.52	0.00007	-0.10	0.13	0.59	[0.87]		0.92	[0.85]	0.21	0.02
18 Proximal When Warm Night&Day	5	9.6	0.91	0.17	[0.55]		0.16	[0.51]		0.18	[0.59]	0.04	0.78	-0.09	0.15	0.30	[0.61]		0.27	[0.60]	0.20	0.03
19 Proximal When Cold Day	5	8.8	0.89	0.07	[0.57]		0.02	[0.55]		0.13	[0.58]	0.19	0.14	-0.06	0.38	0.21	[0.66]		0.24	[0.48]	0.27	0.003
20 Proximal When Cold Night	4	9.7	0.93	-0.03	[0.72]		-0.05	[0.69]		0.00	[0.76]	0.06	0.66	-0.09	0.18	0.07	[0.74]		0.02	[0.72]	0.10	0.28
21 Inside (Warm or Cool, Day or Night)	4	7.1	0.88	0.23	[0.60]		0.15	[0.51]		0.31	[0.68]	0.28	0.03	-0.20	0.002	0.35	[0.64]		0.59	[0.75]	0.37	0.00007
30 62.1 0.91																						

Bold numbers highlight means that are different (see Results section for details and significant differences after correction for multiple comparisons) between people without sleep complaints vs. those with probable insomnia and between males and females without sleep complaints, and significant age correlations. *d*(M-F) and *P*(M-F) = effect size and significance of male-female difference; *r* = Pearson correlation. *P*(*r* Age) = significance of correlation with age; *d*(I-C) and *P*(I-C) = effect size and significance of difference between people with probable insomnia and those without sleep complaints; # = number of items in component and in total; %Var = variance explained by component and in total; *r*(PCA) = correlation of PCA factor scores with component calculated by simply averaging (sign-corrected) items, and their average correlation; St.Dev. = standard deviation, shown between square brackets; ISI = Insomnia Severity Index; PSQI = Pittsburgh Sleep Quality Index; Auton. = Autonomic; Thermoreg. = Thermoregulation; Behav. = Behavioral; Env. = Environments; Pref. = Preferences.

a common underlying component. For a comprehensive overview of the method we refer to Field.⁴² In brief, PCA searches for clusters within the correlation matrix between all items. The resulting clusters, also referred to as components or dimensions, can be ranked with respect to the amount of variance that they explain in the data set, using a measure called eigenvalue. PCA results in a list of the loadings of each item on every extracted component. To facilitate interpretation of components, the dimensional orientation among components is sometimes rotated. Different rotation methods exist that either render the resulting components to be independent (orthogonal rotation, like varimax), or allow for correlations among them (oblique rotation, like promax). As a rule of thumb, components with an eigenvalue ≥ 1 are deemed of interest as these contribute to the total variance explained in the data. In addition, each component ideally includes at least three items that load strongly on that specific component and weakly on other components; and the clustering of the selected items within the component should have some face validity.

PCA analysis was restricted to the data of the 240 participants without sleep complaints. Components were selected if they (1) had an eigenvalue > 1 , (2) included at least three questions. Components were moreover inspected on whether (3) all questions had an absolute loading of at least 0.32 and (4) recognizable logical consistency with the other questions in the component. Questions that did not fulfill these two criteria were removed.

For the first set of 102 questions pertaining to the strength of thermal experiences compared to other people, 14 components met the criteria, which together accounted for 67.7% of the variance. Table 1 shows that the variance accounted for by the different components ranged from 2.5% for the component “Stress-induced Fatigue” to 11.8% for “Cold & Inactivity-induced Cooling & Thermoregulation.” In two components, the lowest loading question did not meet the criterion of logical consistency of the clustering; these were removed. Of the 102 questions, 91 could clearly be assigned to a single component, where they had their strongest absolute loading ranging between $|0.34|$ and $|0.89|$ (mean \pm standard deviation: 0.71 ± 0.12). The number of questions accommodated by the components ranged between 3 and 16. We subsequently inspected whether future use could be facilitated by calculating component scores by just

averaging the scores of all questions attributed to a component instead of calculating factor scores. For two items in one factor this was done after inverting their sign given their negative factor loadings (# 53 and #71, see Appendix 1 and 2). As indicated in Table 1, all simple linear compositions (sign-corrected average) of the component variables had acceptable to strong correlations with their corresponding PCA factor scores (range $r = 0.67$ – 0.95 , average 0.84). An ancillary PCA using Promax oblique rotation was performed to evaluate the robustness of the solution, which resulted in the same components with only small differences in the assignment of questions to components; nine components included exactly the same questions, one component included one different question, two components included one question more, one component included two questions more, and one component included three questions less. All in all, 87 out of 91 questions were assigned to the same components irrespective of the choice of rotation (Varimax orthogonal, Promax oblique), supporting the robustness of the solution.

For the second set of 32 questions pertaining to the relative strength of thermal experiences across different body locations, 7 components met the criteria, which together accounted for 62.1% of the variance. Table 1 shows that the variance accounted for by the different components ranged from 7.2% for the component “Inside (Warm or Cool, Day or Night)” to 10.2% for “Distal When Warm - Day.” Of the 32 questions, 30 could clearly be assigned to a single component, where they had their strongest absolute loading ranging between 0.48 and 0.82 (mean \pm standard deviation: 0.69 ± 0.09). The number of questions accommodated by the components ranged between 3 and 5. As was the case for the first set of items, future use could be facilitated by calculating component scores by just averaging the scores of all questions attributed to a component instead of calculating factor scores. None of the items required inverting their sign given all positive factor loadings. As indicated in Table 1, all simple linear compositions (average) of the component variables correlated strongly with their corresponding PCA factor scores (range $r = 0.87$ – 0.96 , average 0.91). An ancillary PCA using Promax oblique rotation was performed to evaluate the robustness of the solution, which resulted in the same components, with only small differences in the assignment of questions to components; four components included exactly the same questions, one component included one different question, one component included

one question more, two components included one question less. All in all, 27 out of 30 questions were assigned to the same components irrespective of the choice of rotation (Varimax orthogonal, Promax oblique), supporting the robustness of the solution.

Description of components

The variance in the list of 102 questions pertaining to the strength of thermal experiences compared to others could be summarized by fourteen independent components. A complete description of the components and the loadings of questions is given in Appendix 2, but a summary of the fourteen components is given below.

Five components on experiencing body warming, body cooling and thermoregulation

1. *Heat-Induced Warming* included five questions on the effect of a warm environment on the temperatures experienced at several sites of the body.
2. *Activity-Induced Warming* included five questions on the effect of physical exertion on the temperatures experienced at several sites of the body.
3. *Heat- & Activity-Induced Autonomic Thermoregulation* included four questions on the effect of a warm environment or physical exertion on thirst and sweating.
4. *Heat-Induced Behavioral Thermoregulation* included six questions on the effect of a warm environment on thermoregulatory behaviors like finding a cooler place and dressing less warm.
5. *Cold- & Inactivity-Induced Cooling & Autonomic & Behavioral Thermoregulation* was the largest component and included 16 questions that integrated the effects of a cold environment or sitting still on the temperatures experienced at several sites of the body, on autonomic thermoregulation including shivering and chattering teeth, and on behavioral thermoregulation including cold avoidance and turning up the heating.

Two components on experiencing environmental heat and cold:

6. *Heat Perception* included seven questions on the sensitivity to experience heat in several contexts.

7. *Cold Perception* included seven questions on the sensitivity to experience cold in several contexts.

Two components on warmth-seeking behaviors and preferences:

8. *Warmth-Seeking Behaviors and Preferences in Warm Environments* included seven questions reflecting warmth-seeking behaviors and preferences in relatively warm or shielded conditions including liking a warmer home, bed and bedroom and dressing warmer day and night.
9. *Warmth-Seeking Behaviors and Preferences in Cold Environments* included five questions reflecting warmth-seeking behaviors and preferences in relatively cold environments including finding a warmer place, avoiding a cool place, wind or draft, eating or drinking something warm, and dressing warmer. We excluded item 88, "Compared to others, tension, stress or anxiety makes me feel alert." The item loaded stronger on this component than on any other component, yet still quite weakly (-0.35) and seemed illogical among the other items that clearly addressed warmth-seeking behaviors and preferences in cold environments.

Two components on experiencing effects of stress on body warming or cooling:

10. *Stress-Induced Warming* included nine questions on the effect of tension, stress, or anxiety on the warmth experienced at several sites of the body, on autonomic thermoregulatory-like responses of sweating and thirst, and on fatigue, which may facilitate the behavioral thermoregulatory-like response of lowering the level of physical activity.
11. *Stress-Induced Cooling* included five questions on the effect of tension, stress, or anxiety on feeling cold, experienced at several sites of the body.

Two components on experiencing effects of temperature on fatigue:

12. *Heat & Activity-induced Fatigue* included eight questions on the effect of a warm environment or physical exertion on fatigue.
13. *Cold-Induced Fatigue* included four questions on the effect of a cool environment on fatigue.

One component on experiencing effects of stress on fatigue:

14. *Stress-induced Fatigue* included three questions on the effect of tension, stress, or anxiety on fatigue. We excluded item 92, "Compared to others, tension, stress or anxiety give me trouble to warm up afterwards." The item loaded stronger on this component than on any other component (0.58) seemed illogical among the other items that clearly addressed stress-induced fatigue.

PCA on the questions pertaining to the relative strength of thermal experiences across different body locations yielded the following seven components.

Three components on distal temperature experiences:

15. *Distal When Warm - Day* included three questions on feeling warmth more at the hands, arms and feet during daytime.
16. *Distal When Warm - Night* included four questions on feeling warmth more at the hands, arms, feet and legs during nighttime.
17. *Distal When Cold - Night & Day* included five questions on feeling cold more at the hands, feet, and legs during day- and nighttime.

Three components on proximal temperature experiences:

18. *Proximal When Warm - Night & Day* included five questions on feeling warm more at the trunk and legs during day- and nighttime.
19. *Proximal When Cold - Day* included five questions on feeling cold more at the trunk, head and arms during daytime.
20. *Proximal When Cold - Night* included four questions on feeling cold more at the trunk, head and arms during nighttime.

One component on internal temperature experiences:

21. *Inside (Warm or Cool, Day or Night)* included four questions on feeling temperature more internally during day- and nighttime.

Examples of application

Table 1 shows that the simple linear composition (sign-corrected average) of the component variables did not average out to zero, suggesting that for some

components the majority of respondents systematically regarded themselves more sensitive or less sensitive than others. On average, participants rated themselves to be more sensitive than others on eight of the fourteen components pertaining to the strength of thermal experiences, and less sensitive than others on the other six components. People rated themselves most similar to others for stress-induced warming (component 10) and fatigue (component 14), most markedly less sensitive than others to experience warmth-seeking behaviors and preferences in warm environment (component 8) and most markedly more sensitive than others to experience activity-induced warming (component 2), warmth-seeking behaviors and preferences in cold environments (component 9) and heat-induced behavioral thermoregulation (component 4). Table 1 shows moreover that for components pertaining to the relative strength of thermal experiences across different body locations, respondents on average were most likely to experience being warm, and especially being cold, at distal parts of their body (components 15-17), followed by perceiving temperature internally (component 21), and less likely to have proximal experiences of being warm (component 18), even less so for being cold (components 19-20).

Table 1 also shows marked sex differences in the group of respondents who did not experience sleeping problems. Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ males and females differed significantly on five of the fourteen components pertaining to the strength of thermal experience compared to other people. The most significant difference was that females rated themselves more sensitive than others to experience cold- and inactivity-induced cooling and autonomic and behavioral thermoregulation (component 5, $P = 0.0003$); males in contrast rated themselves less sensitive than others on this component. In agreement, a similar sex difference was present for the sensitivity to experience cold (component 7, $P = 0.002$). Both males and females rated themselves less likely than others to show warmth-seeking behaviors and preferences in warm environments, and males even less so than females (component 8, $P = 0.003$). In contrast, both males and females rated themselves more likely than others to show warmth-seeking behaviors and preferences in cold environments, and females even more so than males (component 9, $P = 0.002$). Males felt less likely to experience cold in case of stress if they

compared themselves to others, while females rated themselves equally likely as others to experience cold in case of stress (component 11, $P = 0.004$). **Figure 1**, upper panel, shows a radar-plot of fingerprints (profiles) summarizing the average ratings of males and females on the fourteen components pertaining to the strength of thermal experience compared to other people. Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ males and females also differed on one of the seven components pertaining to the relative strength of thermal experiences across different body locations. Females were much more likely than males to experience being cold at distal parts of their body (component 17, $P = 0.00007$). **Figure 1**, lower panel, shows a radar-plot of fingerprints (profiles) summarizing the average ratings of males and females on the seven components pertaining to the relative strength of thermal experiences across different body locations.

Another example of the use of the Experienced Temperature Sensitivity and Regulation Survey (ETSRS) concerns individual differences related to aging. We studied the effect of age on ETSRS scores in the groups of subjects who did not suffer from probable insomnia. Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ age was significantly associated with two of the fourteen components pertaining to the strength of thermal experiences compared to other people. These effects of age concerned a decrease in experienced warming up from physical activity (component 2, $r = -0.23$, $P = 0.0004$) and in heat- or physical activity-induced fatigue (component 12, $r = -0.19$, $P = 0.003$). While not surviving the correction for multiple comparisons, possible other effects of age concerned a decrease in experienced warming up from stress (component 10, $r = -0.17$, $P = 0.007$), decreases in heat perception (component 6, $r = -0.15$, $P = 0.02$), heat- and activity-induced autonomic thermoregulation (component 3, $r = -0.14$, $P = 0.03$), and in heat-induced warming (component 1, $r = -0.14$, $P = 0.04$) or behavioral thermoregulation (component 4, $r = -0.13$, $P = 0.04$). **Figure 2**, upper panel, shows a radar-plot with a fingerprint summarizing the correlations of age with each of the fourteen components pertaining to the strength of thermal experience compared to other people.

Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ age was also significantly associated with one of the seven components pertaining to the relative strength of thermal experiences across different body locations: older people experienced less internal sensations of heat or cold (component 21, $r = -0.20$, $P = 0.002$). **Figure 2**, lower panel, shows a radar-plot with a fingerprint summarizing the correlations of age with each of the seven components pertaining to the relative strength of thermal experiences across different body locations.

A final example of the use of the ETSRS concerns the study of individual differences in temperature experience related to insomnia. Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ people with probable insomnia differed on five of the fourteen components pertaining to the strength of thermal experiences compared to other people. As compared to those without sleep complaints, people with probable insomnia considered themselves, in decreasing order of significance, to experience more fatigue induced by heat or physical activity (component 12, $P = 3 \times 10^{-7}$), by stress (component 14, $P = 0.00001$) and by cold (component 13, $P = 0.0004$). They also considered themselves to experience more cold- and inactivity-induced cooling and autonomic and behavioral thermoregulation (component 5, $P = 0.001$) and to experience more cold (component 7, $P = 0.002$). While not surviving the correction for multiple comparisons, possible other characteristics of people with probable insomnia are that they showed more warmth-seeking behaviors and preferences in cold environments (component 9, $P = 0.02$), and considered themselves to experience heat quicker than others (component 6, $P = 0.02$). **Figure 3**, upper panel, shows a radar-plot of fingerprints summarizing the average ratings of people with probable insomnia and those without sleep complaints on the fourteen components pertaining to the strength of thermal experience compared to other people.

Using a sequentially rejective adapted Bonferroni approach to account for multiple testing,⁴³ people with probable insomnia also differed on two of the seven components pertaining to the relative strength of thermal experiences across different body locations. As compared to those without sleep complaints, people with probable insomnia considered themselves to have stronger internal sensations of being warm or cold (component 21, $P = 0.00007$), and to feel cold

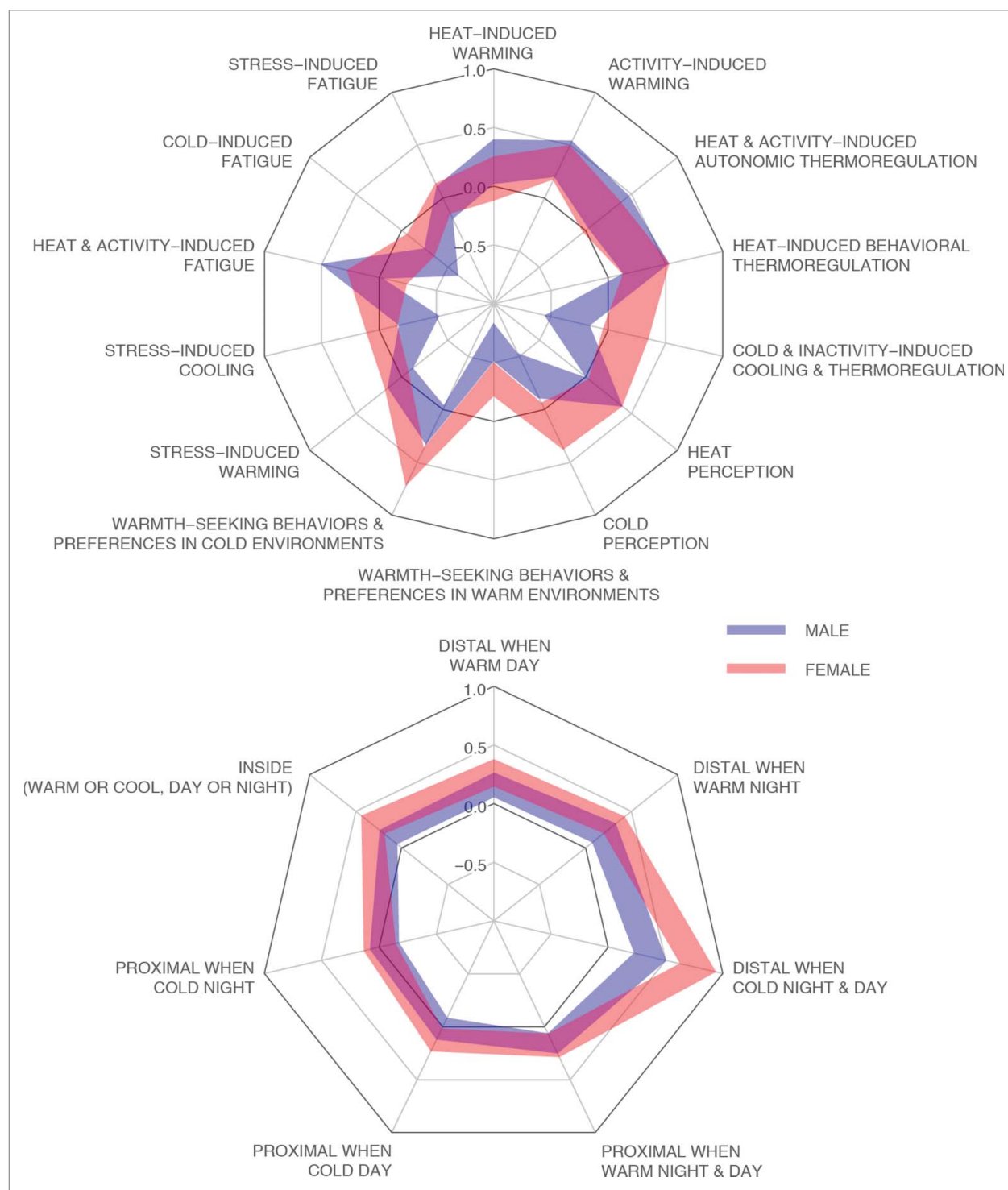


Figure 1. Upper Panel: Radar-plot of fingerprints summarizing the 95% confidence intervals of the ratings of males (blue) and females (red) on the fourteen components pertaining to the strength of thermal experience compared to other people. Females rated themselves more sensitive than males to experience cold- and inactivity-induced cooling and autonomic and behavioral thermoregulation (component 5); to experience cold (component 7) and to show warmth-seeking behaviors and preferences in warm (component 8) and cold (component 9) environments; and to experience cold in case of stress (component 11). **Lower Panel:** Radar-plot of fingerprints summarizing the 95% confidence intervals of the ratings of males (blue) and females (red) on the seven components pertaining to the relative strength of thermal experiences across different body locations. Females were significantly more likely than males to experience being cold at distal parts of their body (component 17).

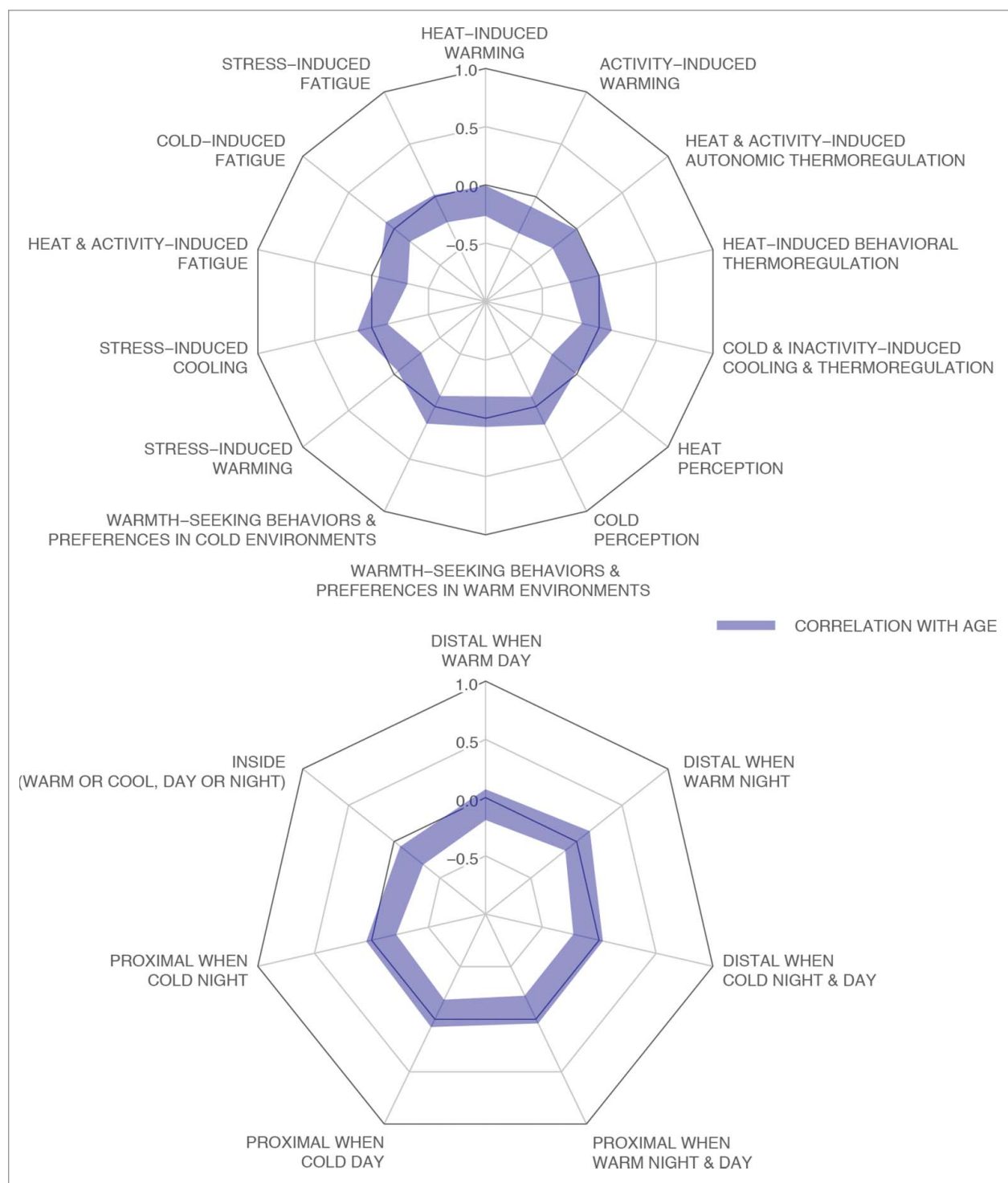


Figure 2. Upper Panel: Radar-plot with a fingerprint summarizing the 95% confidence intervals of the correlations of age with each of the fourteen components pertaining to the strength of thermal experience compared to other people. Increasing age was significantly associated with a decrease in experiencing warming up from physical activity (component 2) and heat- or physical activity-induced fatigue (component 12). Marginally significant other suggestive associations of increasing age were decreases in experiencing warming up from stress (component 10), heat perception (component 6), heat- and activity-induced autonomic thermoregulation (component 3), and heat-induced warming (component 1) or behavioral thermoregulation (component 4). Lower Panel: Radar-plot with a fingerprint summarizing the 95% confidence intervals of the correlations of age with each of the seven components pertaining to the relative strength of thermal experiences across different body locations. Increasing age was significantly associated with experiencing less internal sensations of heat or cold (component 21).

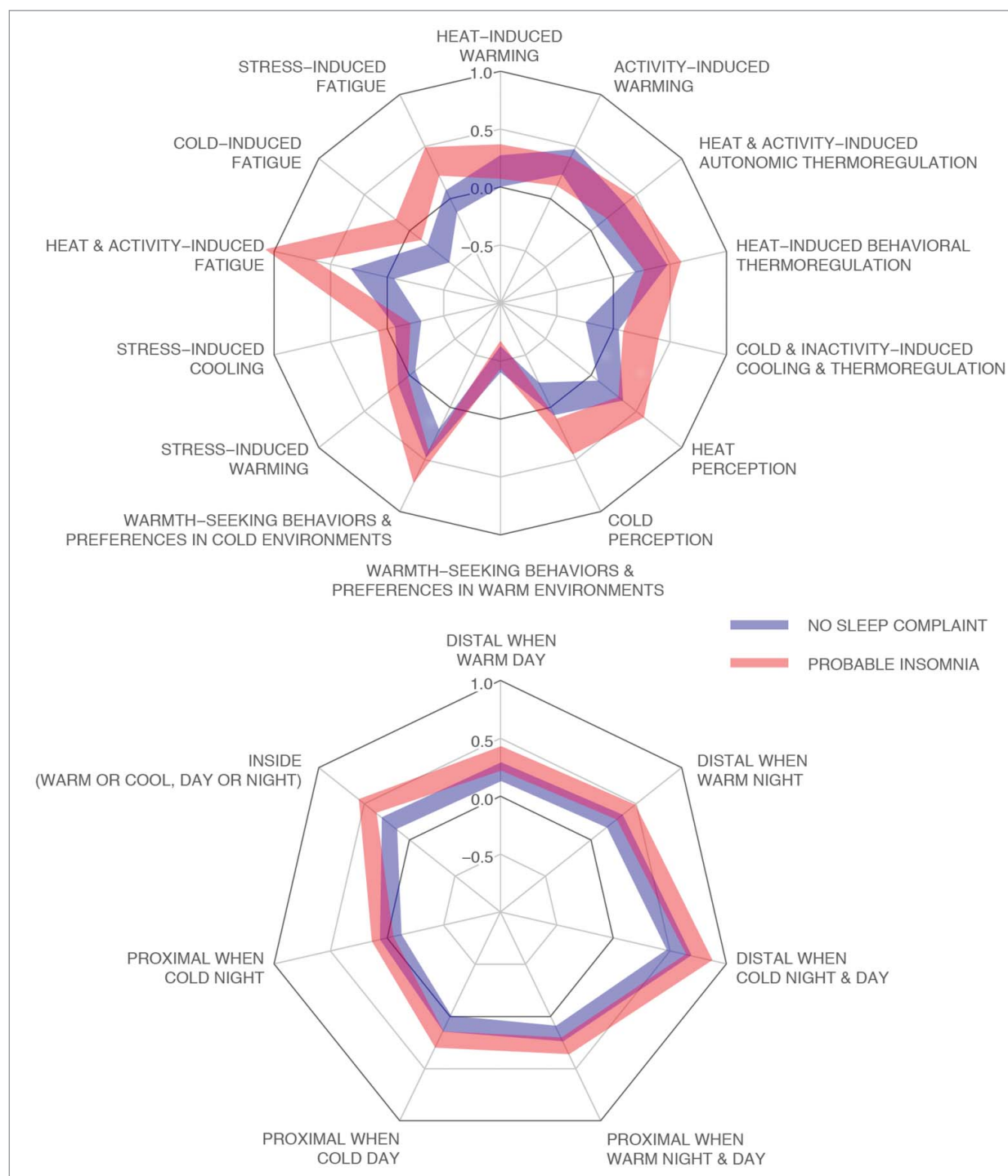


Figure 3. Upper Panel: Radar-plot of fingerprints summarizing the 95% confidence intervals of the ratings of people with probable insomnia (red) and those without sleep complaints (blue) on the 14 components pertaining to the strength of thermal experience compared to other people. People with insomnia rated themselves more sensitive than people without sleep complaints to experience fatigue induced by heat or physical activity, by cold and by stress (component 12-14). They also considered themselves to experience more cold- and inactivity-induced cooling and autonomic and behavioral thermoregulation (component 5) and to experience more cold (component 7). Marginally significant other characteristics of people with probable insomnia were more warmth-seeking behaviors and preferences in cold environments (component 9), and experiencing heat quicker than others (component 6). **Lower Panel:** Radar-plot of fingerprints summarizing the 95% confidence intervals of the ratings of people with probable insomnia (red) and those without sleep complaints (blue) on the seven components pertaining to the relative strength of thermal experiences across different body locations. People with probable insomnia were significantly more likely to experience being warm or cold internally (component 21), and to feel cold during daytime more at the proximal part of the body (component 19). Marginally significant other characteristics of people with probable insomnia were feeling cold more at the distal part of the body (component 17), and feeling warm more at the proximal part of the body (component 18).

during daytime more at the proximal part of the body (component 19, $P = 0.003$). While not surviving the correction for multiple comparisons, possible other characteristics of people with probable insomnia are that they feel cold more at the distal part of the body irrespective of the time of day (component 17, $P = 0.02$), and feel warm more at the proximal part of the body (component 18, $P = 0.03$). **Figure 3**, lower panel, shows a radar-plot of fingerprints summarizing the average ratings of people with probable insomnia and those without sleep complaints on the seven components pertaining to the relative strength of thermal experiences across different body locations.

Discussion

Aiming to resolve the current lack of an instrument to comprehensively assess trait-like experiences of temperature sensitivity and regulation, the present study introduced and evaluated a pool of questions surveying the experience of several domains of temperature sensitivity and regulation in a variety of contexts. Principal component analyses indicated that the majority of the questions grouped in meaningful components that turned out to be sensitive to individual differences related to sex, age and probable insomnia.

Fourteen components emerged as different dimensions from the list of questions pertaining to the strength of thermal experiences compared to others. The largest component (5) integrated 16 questions on cold- and inactivity-induced cooling and autonomic and behavioral thermoregulation. In contrast, the corresponding opposed concepts for heat- and activity-induced warming and autonomic and behavioral thermoregulation were separated as six separate dimensions (1-4, 8,9). The marked difference suggests that people experience signs of cooling down and the corresponding cold defense mechanisms in a rather integrated way, whereas they have more differentiated experiences of warming up and the corresponding heat loss mechanisms. Sensitivities to notice heat and cold were represented as two different dimensions, supporting the interpretation that the questions did not merely reflect a tendency to report high or low sensitivity in general. It appeared useful to include questions on the vigilance effects of temperature; two different dimensions appeared, plus one on the effect of stress on vigilance. Likewise, it appeared useful to include questions on behavioral and autonomic

responses to stress that resemble similar responses to heat or cold; three different dimensions emerged. In contrast, questions on behavioral and autonomic responses to exertion and inactivity that resemble similar responses to heat or cold respectively did not emerge as separate dimensions but rather as integrated with questions addressing heat or cold exposure. Whereas seasonal and diurnal contexts did not emerge as separate dimensions, the doubling of several questions within these contexts allows for refined investigations of dependency on season or time of day by comparing top-down selected sets of corresponding questions.

Seven components emerged as different dimensions from the list of questions pertaining to the relative strength of thermal experiences across different body locations. The components were very similar in the amount of variance they accounted for. Three distal components, three proximal components, and one component relating to internal sensitivity appeared as recognizable different dimensions. Separate dimensions emerged for the daytime- versus nighttime sensitivity to both distal heat responses as well as proximal cold responses. Daytime and nighttime sensitivities were not discriminated however for distal cold responses and proximal heat responses. Sensitivity to internal temperature did not discriminate between daytime and nighttime, nor between heat and cold. Arms and legs were rather inconsistently emerging within either distal or proximal components, possibly reflecting the physiological ambivalence of their physiology that can correspond to either the trunk vs. extremities in case of, respectively, exposure to cold, an upright posture or wakefulness versus exposure to heat, a supine posture or sleep.^{44,45} Upper and lower extremities did not appear as different dimensions, suggesting that the experience of their temperatures is integrated, at least in normal everyday life conditions. Interestingly, whereas the physiological fluctuations and responses of upper and lower extremities may indeed be synchronized under normal conditions, a recent study showed that they may diverge under the extreme condition of maintaining wakefulness without any sleep for more than 24 hours.³² The pool of questions of the ETSRS allows for a follow up on these findings. Even though upper and lower extremities are not separately represented in different PCA-derived components, the doubling of several questions for both upper- and lower extremities makes it possible to

calculate averages of top-down selected sets of corresponding questions. Future studies may investigate the use of both PCA-derived components and top-down enforced averages over e.g. upper and lower extremities, in disorders where localized deviations would be of interest, like diabetes-related neuropathy.

Irrespective of the choice of rotation (Varimax orthogonal, Promax oblique), the same number of components emerged in the PCA. Moreover, the majority (94%) of the questions were assigned to the same component. Whereas these observations support robustness of the PCA solution, independent studies will be required to evaluate whether the solution generalizes to other population samples.

It has not been the aim of the present study to provide a detailed in-depth account of sex-, age- and probable insomnia-related individual differences in either objective or subjectively experienced thermosensitivity and thermoregulation. On the contrary, the aim was to develop an instrument that could be used to facilitate future in depth studies on individual differences in such subjective experiences, as well as how they relate to individual differences in objective parameters of thermosensitivity and thermoregulatory capacity. Accordingly, the present findings will only briefly be summarized.

The present findings complement the observations from experimental studies by demonstrating that sex differences are also present in the subjective experience of thermosensitivity and thermoregulation in everyday life. The overarching consistency of findings was that women are more likely to feel cold and accordingly experience autonomic and behavioral thermoregulatory responses. With respect to differential experiences across locations of the body, females also have more internal experiences of their body temperature and more distal experiences of cold.

A marked finding of the present application of the ETSRS to study associations with aging is that with increasing age, people experience less and less warming up from physical activity. The finding is consistent with the objective observation that moderate physical activity elicits a smaller increase in core temperature in elderly people.⁴⁶ Although not reaching significance when correcting for multiple comparisons, the same decrease may be present in warming up from non-physical stress, supporting the value of evaluating this domain. Another

marked association was the age-related decrease in experiencing fatigue in response to heat exposure or physical activity. The finding of a decreased probability of experiencing fatigue is consistent with the finding that daytime sleepiness is not common during healthy aging and that elderly people tolerate sleep deprivation even better than younger people.⁴⁷ Although not reaching significance when correcting for multiple comparisons, the present findings also suggest that elderly may be less likely to experience heat and associated internal warming and thermoregulatory responses, in agreement with objective physiological assessments of heat induced thermoregulatory responses.^{20,48}

The value of the ETSRS was also demonstrated in the comparison of the sample without sleep complaints with a matched group of people with probable insomnia disorder. Applying the ETSRS in this case-control approach, it showed to be sufficiently sensitive to detect multiple group differences with strong statistical significance. Two components show that people with probable insomnia are more likely to experience fatigue if temperature deviates from the thermoneutral zone. This may be a non-specific generalized response to deviations from any neutral or homeostatically balanced condition, because a third component shows that people with probable insomnia also show increased fatigue in response to physical activity and stress. The suggestion of nonspecificity would not have emerged without the questions about stress and vigilance, underscoring their value as part of the ETSRS. Two components indicate that people with probable insomnia are more likely to feel cold and to experience autonomic and behavioral thermoregulatory responses. The enhanced cold sensitivity reminds of rat studies showing that chronic sleep deprivation lowered core body temperature and energy metabolism in brain regions involved in thermoregulation and sleep.^{49,50} People with probable insomnia also differed on two of the seven components pertaining to the relative strength of thermal experiences across different body locations. It would be interesting to evaluate how enhanced internal sensations of feeling warm or cold and enhanced proximal sensations of feeling cold during daytime relate to objective assessments of the distribution of temperatures across the body and their relevance

for sleep onset and sleep depth.^{51,52} The present findings suggest that a multivariate fingerprint of significantly different experienced autonomic or behavioral thermoregulatory activity can be used to discriminate people with probable insomnia from those without sleep complaints.

In summary, we here introduced the Experienced Temperature Sensitivity and Regulation Survey (ETSRS), and showed the use of this pool of questions to comprehensively assess trait-like experiences of temperature sensitivity and regulation. Future studies may make use of the ETSRS to investigate, to name a few: deviations in disorders; changes induced by specific chronic exposures including temperature acclimatization; associations with objective thermoregulatory sensitivity and capacity; value for optimization of indoor climates. As shown in Table 1, Cohen's d effect sizes for components with significant group differences were in the range of small ($d = 0.20$) to medium ($d = 0.50$). If similar differences are expected for case-control studies, these effect sizes can be used for *a priori* calculations of the sample size required in such future studies. Data-collection in reasonable sample sizes may be facilitated by online internet data collection: the survey is available in LimeSurvey (www.limesurvey.org) format, as for example was implemented on www.sleepregistry.nl, the source of the currently used data. On request we can make an Excel (Microsoft, Redmond, WA, USA) sheet available for automated calculation of component scores based on the PCA results as well as averages of top-down selected sets of corresponding questions to zoom in on differential sensitivities in the contexts of wake vs. sleep, winter versus summer, cold vs. warm environments and upper versus lower parts of the body. As is the case for almost all questionnaires, its use will most likely result in adaptations, refinements and possibly a brief version. We welcome and hope to support many researchers and clinicians that are interested to use or further develop the ETSRS.

Materials and methods

Question generation

Questions were generated with the help of an expert panel consisting of researchers participating in ThermoNed. The questions were generated to cover six

domains of experienced temperature sensitivity and regulation. In each domain, several categories could be defined, as described below.

Input/perturbation. The first domain accommodates four categories that describe *type of input / perturbation* impinging on the thermoregulatory system. In addition to the obvious categories of exposure to Heat and Cold, two additional categories could be of interest: Physical Activity and Stress. Several sensations and behavioral or autonomic responses to heat or cold occur as well in response to different levels of physical activity or stress. People may differ for example in the extent to which they feel cold when sedentary, warm up and experience thermoregulatory responses with physical activity, and feel warm or cold, or experience autonomic responses like sweating under stressful circumstances. By assessing thermoregulatory experiences and responses with respect to Physical Activity and Stress as well, it becomes feasible to investigate input-specificity of individual differences in the reported experiences of regulation and sensitivity.

Readout. The second domain accommodates six categories that describe *type of output or readout* from the thermosensitive and thermoregulatory system. The first category concerns the subjective Preference for warmer or colder circumstances. The second category concerns Sensing Deviation. For instance, elderly people regulate their indoor ambient temperature less precisely, and tolerate larger deviations from a comfortable range before they undertake a behavioral thermoregulatory action (reviewed in ^{20,53}). The third category is the experienced Subjective Body Temperature, describing the extent to which an individual feels warm or cold. The fourth category is the Autonomic Response that people notice. The category includes e.g., shivering, sweating and the speed of recovery from exposure to heat or cold. The fifth category is the Behavioral Response, including clothing choice, finding a cooler or warmer place and manipulating environmental temperature. Finally, a sixth category of questions was added to assess the Vigilance Response people may experience to heat or cold. Several studies show that subjective and objective sleepiness respond to changes in temperature, even if these changes are small and within the thermoneutral range (reviewed in ⁵⁴).

Homeostatic Drive. The third domain concerns three *homeostatic drive* categories that questions can refer to. In addition to the obvious homeostatic thermoregulatory system categories of Heat Loss and Heat Preservation, one category was added to accommodate questions that refer to the vigilance-regulating system, e.g. sleepiness.

Seasonal Context. To cover seasonal differences, in the fourth domain questions were formulated to evaluate season-specific temperature preferences and thermoregulatory behavior. Nine questions were administered twice, once referring to the summer period, and once referring to wintertime.

Sleep-Wake context. Temperature regulation, sensitivity, and preference may vary not only with season, but also with the circadian temporal context. Whereas demanding laboratory protocols allow us to disentangle circadian rhythm-related variation from sleep-wake state related variation, the two are usually indistinguishable in real life. In the fifth domain, Sleep and Wake categories were distinguished, such that questions were posed within the context of the night and sleep or within the context of daytime wakefulness.

Body Location. The final domain concerns five body locations that the questions refer to: the Head; the Distal parts of the body (i.e. hands and feet); the Proximal part of the body (e.g., trunk); Internally; or Unspecified (i.e., questions could not refer specifically to a particular part of the body).

A total of 136 questions were generated. For a first set of 102 questions, participants were asked to compare their thermal experiences to others on a 7-point bi-directional Likert scale. For a second set of 32 questions, participants are asked to use a 7-point bi-directional Likert scale to indicate the relative strength of experiences across different body locations. Two additional questions asked for the nocturnal and diurnal settings of the central heating thermostats at home during the summer and winter. These two questions were, however, not included in the current analyses. All questions are listed in Appendix 1.

Internet assessment procedure

The questions were implemented as a survey for internet assessment on the Netherlands Sleep Registry

(NSR) website (www.sleepregistry.nl). The NSR is a national platform that recruits volunteers by advertising in media (internet, television, radio, magazines, newspapers) and through flyers distributed in health care institutions and conventions. People are asked to fill out questionnaires regularly in order to help create a psychometric database to facilitate research on components that discriminate people with probable insomnia from those without sleep complaints; there is no particular focus on thermoregulation. Continued commitment of the unpaid volunteers is supported by newsletters, reminder emails, and occasional voucher lottery. The Medical Ethical Committee of the Academic Medical Center of the University of Amsterdam as well as the Central Committee on Research Involving Human Subjects (CCMO), The Hague, The Netherlands, approved of unsigned informed consent because volunteers participated anonymously without revealing their full name and address and were not exposed to any intervention or behavioral constraint.

Participants

The present investigation included a selection of 480 participants from the NSR. Age of participants ranged between 20 and 70 years. The age range was deliberately chosen wide to allow for an investigation of age-related changes in ETSRS scores. Two hundred and forty (120 male and 120 female) participants were included who did not suffer from sleep complaints as indicated by validated cut-off scores ≤ 5 on the Pittsburgh Sleep Quality Index (PSQI)⁴⁰ and <10 on the Insomnia Severity Index (ISI).⁴¹ To further illustrate the applicability of the ETSRS to evaluate group differences, age-matched samples of 120 males and 120 females were selected on the basis of probable insomnia disorder, according to cut-off scores of >5 and ≥ 10 respectively.

Analysis: dimension reduction

Principal components analysis with Varimax-rotation was applied as a data reduction method on the 240 subjects without sleep complaints, in order to reduce the multivariate dimensionality without making *a priori* assumptions about associations between questions. Analyses used IBM SPSS Statistics (Version 22, Chicago, IL). Components were selected if they (1) had an eigenvalue >1 and (2) included at least three

questions. Components were moreover inspected on whether (3) all questions had an absolute loading of at least 0.32 and (4) recognizable logical consistency with the other questions in the component. Questions that did not fulfill these two criteria were removed. Separate principal component analyses were performed for the 102 questions pertaining to the strength of thermal experiences compared to other people, and for the 32 questions pertaining to the relative strength of experiences across different body locations. To simplify future analyses, we calculated the mean component scores not from the loadings but by just averaging the scores on the items within a component, after inverting their sign given their negative factor loadings (# 53 and #71). It should be noted that although we here report these component scores, several of the questions are repeatedly asked in different contexts, allowing the user to also calculate averages of top-down selected sets of corresponding questions to zoom in on differential sensitivities in the contexts of wake vs. sleep, winter versus summer, cold vs. warm environments and upper versus lower parts of the body.

Analysis: individual differences related to sex, age, and probable insomnia

Group characteristics are presented as averages with standard deviation. Group differences were evaluated using two-sided *t*-tests not presuming equal variances. Pearson's *r* correlations were calculated to describe associations of age with subjectively experienced thermosensitivity and thermoregulation. Their significance was evaluated using *t* transformations⁵⁵ and two-sided *t*-tests. To account for multiple testing we used a sequentially rejective adapted Bonferroni approach⁴³ with an overall two-sided $\alpha < 0.05$.

Abbreviations

ETSRS	Experienced Temperature Sensitivity and Regulation Survey
ISI	Insomnia Severity Index
ISO	International Standards Organization
NSR	Netherlands Sleep Registry
PCA	Principal Component Analysis
PSQI	Pittsburgh Sleep Quality Index

Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

Acknowledgments

We acknowledge all people of the ThermoNed Group that provided suggestions for topics to be covered by questions, and thank all participants of the Netherlands Sleep Registry for filling out questionnaires. Translations of questionnaires was supported by Iuliana Hartescu, NIHR BioMedical Research Unit, School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, United Kingdom.

Funding

This work was supported by Projects NeuroSIPE 10738 and OnTime 12188, of the Dutch Technology Foundation STW, which is part of the Netherlands Organization for Scientific Research (NWO) and partly funded by the Ministry of Economic Affairs, Agriculture and Innovation; both in The Hague, the Netherlands; the FP7-PEOPLE-ITN-2008 Marie Curie Actions Networks for Initial Training (ITN) funding scheme, grant number 238665, project Neuroendocrine Immune Networks in Aging (NINA); by the VICI Innovation Grant 453-07-001 of the Netherlands Organization of Scientific Research (NWO); The Hague, the Netherlands; and by the European Research Council (ERC-ADG-2014-671084 INSOMNIA). SvdS and EA are supported by NWO/MaGW: VIDI-452-12-014 and NWO Aspasia 015.009.016. Work for this study was performed at the Department of Sleep and Cognition, Netherlands Institute for Neuroscience, an Institute of the Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands.

References

- [1] Romanovsky AA. Thermoregulation: some concepts have changed. *Functional architecture of the thermoregulatory system*. *Am J Physiol* 2007; 292:R37-46; PMID:17008453
- [2] Kingma BRM, Frijns AJH, Schellen L, van Marken Lichtenbelt WD. Beyond the classic thermoneutral zone. *Temperature* 2014; 1:142-9; <http://dx.doi.org/10.4161/temp.29702>
- [3] Kingma B, van Marken Lichtenbelt W. Energy consumption in buildings and female thermal demand. *Nature Climate Change* 2015; 5:1054-1056; <http://dx.doi.org/10.1038/nclimate2741>
- [4] Bernhard MC, Li P, Allison DB, Gohlke JM. Warm ambient temperature decreases food intake in a simulated office setting: A pilot randomized controlled trial. *Front Nutri* 2015; 2:20; PMID:26322311
- [5] Fanger PO. *Thermal Comfort*. Copenhagen: Danish Technical Press, 1970
- [6] Parsons K. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort and Performance*. Boca Raton: CRC Press, 2002
- [7] Gagge AP, Stolwijk JAJ, Nishi Y. An effective temperature scale based on a single model of human physiological temperature response. *ASHRAE Transactions* 1971; 77:247-62

- [8] Leon GR, Koscheyev VS, Stone EA. Visual analog scales for assessment of thermal perception in different environments. *Aviat Space Environ Med* 2008; 79:784-6; PMID: 18717119; <http://dx.doi.org/10.3357/ASEM.2204.2008>
- [9] Raymann RJEM, Van Someren EJW. Diminished capability to recognize the optimal temperature for sleep initiation may contribute to poor sleep in elderly people. *Sleep* 2008; 31:1301-9; PMID:18788655
- [10] Gompfer B, Bromundt V, Orgul S, Flammer J, Krauchi K. Phase relationship between skin temperature and sleep-wake rhythms in women with vascular dysregulation and controls under real-life conditions. *Chronobiol Int* 2010; 27:1778-96; PMID:20969523; <http://dx.doi.org/10.3109/07420528.2010.520786>
- [11] Hardy JD, Du Bois EF. Differences between men and women in their response to heat and cold. *PNAS* 1940; 26:389-98; PMID:16588368; <http://dx.doi.org/10.1073/pnas.26.6.389>
- [12] Burse RL. Sex differences in human thermoregulatory response to heat and cold stress. *Human Factors* 1979; 21:687-99; PMID:393617
- [13] Kaciuba-Uscilko H, Grucza R. Gender differences in thermoregulation. *Curr Opin Clin Nutri Metabolic Care* 2001; 4:533-6; PMID:11706289; <http://dx.doi.org/10.1097/00075197-200111000-00012>
- [14] Gagnon D, Kenny GP. Does sex have an independent effect on thermoeffector responses during exercise in the heat? *J Physiol* 2012; 590:5963-73; PMID:23045336; <http://dx.doi.org/10.1113/jphysiol.2012.240739>
- [15] Bao AM, Liu RY, Van Someren EJW, Hofman MA, Cao YX, Zhou JN. Diurnal rhythm of free estradiol during the menstrual cycle. *Eur J Endocrinol* 2003; 148:227-32; PMID:12590642; <http://dx.doi.org/10.1530/eje.0.1480227>
- [16] Boulant JA, Silva NL. Neuronal sensitivities in preoptic tissue slices: interactions among homeostatic systems. *Brain Res Bull* 1988; 20:871-8; PMID:3044526; [http://dx.doi.org/10.1016/0361-9230\(88\)90104-9](http://dx.doi.org/10.1016/0361-9230(88)90104-9)
- [17] DeGroot DW, Kenney WL. Impaired defense of core temperature in aged humans during mild cold stress. *Am J Physiol* 2007; 292:R103-8
- [18] Havenith G, Inoue Y, Luttikholt V, Kenney WL. Age predicts cardiovascular, but not thermoregulatory, responses to humid heat stress. *Eur J Appl Physiol* 1995; 70:88-96; <http://dx.doi.org/10.1007/BF00601814>
- [19] Holowatz LA, Thompson-Torgerson C, Kenney WL. Aging and the control of human skin blood flow. *Front Biosci* 2010; 15:718-39; PMID:20036842; <http://dx.doi.org/10.2741/3642>
- [20] Van Someren EJW, Raymann RJEM, Scherder EJA, Daanen HAM, Swaab DF. Circadian and age-related modulation of thermoreception and temperature regulation: mechanisms and functional implications. *Ageing Res Rev* 2002; 1:721-78; PMID:12208240; [http://dx.doi.org/10.1016/S1568-1637\(02\)00030-2](http://dx.doi.org/10.1016/S1568-1637(02)00030-2)
- [21] Swaab DF, Van Someren EJW, Zhou JN, Hofman MA. Biological rhythms in the human life cycle and their relationship to functional changes in the suprachiasmatic nucleus. *Prog Brain Res* 1996; 111:349-68; PMID: 8990925; [http://dx.doi.org/10.1016/S0079-6123\(08\)60418-5](http://dx.doi.org/10.1016/S0079-6123(08)60418-5)
- [22] Van Veen MM, Kooij JJS, Boonstra AM, Gordijn MCM, Van Someren EJW. Delayed circadian rhythm in adults with ADHD and chronic sleep onset insomnia. *Biol Psychiatry* 2010; 67:1091-6; PMID:20163790; <http://dx.doi.org/10.1016/j.biopsych.2009.12.032>
- [23] 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; PMID:18603220; <http://dx.doi.org/10.1016/j.smrv.2008.02.003>
- [24] Stoffers D, Moens S, Benjamins J, van Tol M-J, Penninx BWJH, Veltman DJ, van der Wee NJA, Van Someren EJW. Orbitofrontal gray matter relates to early morning awakening: a neural correlate of insomnia complaints? *Front Neurol* 2012; 3:105; PMID:23060850; <http://dx.doi.org/10.3389/fneur.2012.00105>
- [25] Weber M, Webb CA, Deldonna SR, Kipman M, Schwab ZJ, Weiner MR, Killgore WD. Habitual 'sleep credit' is associated with greater grey matter volume of the medial prefrontal cortex, higher emotional intelligence and better mental health. *J Sleep Res* 2013; 22:527-34; PMID:23593990; <http://dx.doi.org/10.1111/jsr.12056>
- [26] Craig AD, Chen K, Bandy D, Reiman EM. Thermosensory activation of insular cortex. *Nat Neurosci* 2000; 3:184-90; PMID:10649575; <http://dx.doi.org/10.1038/72131>
- [27] Chowers I, Conforti N, Feldman S. Local effect of cortisol in the preoptic area on temperature regulation. *Am J Physiol* 1968; 214:538-42; PMID:5638986
- [28] Bonnet MH, Arand DL. 24-Hour metabolic rate in insomniacs and matched normal sleepers. *Sleep* 1995; 18:581-8; PMID:8552929
- [29] Stoffers D, Altena E, van der Werf YD, Sanz-Arigita EJ, Voorn TA, Astill RG, Strijers RL, Waterman D, Van Someren EJ. The caudate: a key node in the neuronal network imbalance of insomnia? *Brain* 2014; 137:610-20; PMID:24285642; <http://dx.doi.org/10.1093/brain/awt329>
- [30] Romeijn N, Van Someren EJW. Correlated fluctuations of daytime skin temperature and vigilance. *J Biol Rhythms* 2011; 26:68-77; PMID:21252367; <http://dx.doi.org/10.1177/0748730410391894>
- [31] Ramautar JR, Romeijn N, Gomez-Herrero G, Piantoni G, Van Someren EJW. Coupling of infraslow fluctuations in autonomic and central vigilance markers: Skin temperature, EEG β power and ERP P300 latency. *Int J Psychophysiol* 2013; 89:158-64; PMID:23313606; <http://dx.doi.org/10.1016/j.ijpsycho.2013.01.001>
- [32] Romeijn N, Verweij IM, Koeleman A, Mooij A, Steimke R, Virkkala J, van der Werf Y, Van Someren EJW. Cold hands, warm feet: sleep deprivation disrupts thermoregulation and its association with vigilance. *Sleep* 2012; 35:1673-83; PMID:23204610
- [33] Raymann RJEM, Swaab DF, Van Someren EJW. Skin temperature and sleep-onset latency: Changes with age and insomnia. *Physiol Behav* 2007; 90:257-66;

- PMID:17070562; <http://dx.doi.org/10.1016/j.physbeh.2006.09.008>
- [34] Raymann RJEM, Van Someren EJW. Time-on-task impairment of psychomotor vigilance is affected by mild skin warming and changes with aging and insomnia. *Sleep* 2007; 30:96-103; PMID:17310870
- [35] Altena E, Vrenken H, Van Der Werf YD, Van Den Heuvel OAV, Van Someren EJW. Reduced orbitofrontal and parietal grey matter in chronic insomnia: a voxel-based morphometric study. *Biol Psychiatry* 2010; 67:182-85; PMID:19782344; <http://dx.doi.org/10.1016/j.biopsych.2009.08.003>
- [36] Joo EY, Noh HJ, Kim JS, Koo DL, Kim D, Hwang KJ, Kim JY, Kim ST, Kim MR, Hong SB. Brain gray matter deficits in patients with chronic primary insomnia. *Sleep* 2013; 36:999-1007; PMID:23814336
- [37] Lim ASP, Fleischman DA, Dawe RJ, Yu L, Arfanakis K, Buchman AS, Bennett DA. Regional neocortical gray matter structure and sleep fragmentation in older adults. *Sleep* 2015; online available: <http://www.journalsleep.org/AcceptedPapers/SP-213-15.pdf>; PMID:26350471
- [38] Kringelbach ML. The human orbitofrontal cortex: linking reward to hedonic experience. *Nat Rev Neurosci* 2005; 6:691-702; PMID:16136173; <http://dx.doi.org/10.1038/nrn1747>
- [39] Kringelbach ML, Berridge KC. Towards a functional neuroanatomy of pleasure and happiness. *Trends Cogn Sci* 2009; 13:479-87; PMID:19782634; <http://dx.doi.org/10.1016/j.tics.2009.08.006>
- [40] Buysse DJ, Reynolds CFD, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989; 28:193-213; PMID:2748771; [http://dx.doi.org/10.1016/0165-1781\(89\)90047-4](http://dx.doi.org/10.1016/0165-1781(89)90047-4)
- [41] Morin CM, Belleville G, Belanger L, Ivers H. The insomnia severity index: psychometric indicators to detect insomnia cases and evaluate treatment response. *Sleep* 2011; 34:601-8; PMID:21532953
- [42] Holm S. A simple sequentially rejective multiple test procedure. *Scandinavian J Statistics* 1979; 6:65-70
- [43] Aschoff J. Temperaturregulation. In: Gauer OH, Kramer K, Jung R, eds. *Energiehaushalt und Temperaturregulation Physiologie des Menschen*. Munich: Urban & Schwarzenberg 1971:43-112
- [44] Kräuchi K. The thermophysiological cascade leading to sleep initiation in relation to phase of entrainment. *Sleep Med Rev* 2007; 11:439-51; PMID:17764994; <http://dx.doi.org/10.1016/j.smrv.2007.07.001>
- [45] Falk B, Bar-Or O, Smolander J, Frost G. Response to rest and exercise in the cold: effects of age and aerobic fitness. *J Appl Physiol* 1994; 76:72-8; PMID:8175550
- [46] Duffy JF, Willson HJ, Wang W, Czeisler CA. Healthy older adults better tolerate sleep deprivation than young adults. *J Am Geriatr Soc* 2009; 57:1245-51; PMID:19460089; <http://dx.doi.org/10.1111/j.1532-5415.2009.02303.x>
- [47] Kenney LW. Decreased cutaneous vasodilation in aged skin: mechanisms, consequences and interventions. *J Therm Biol* 2001; 26:263-71; [http://dx.doi.org/10.1016/S0306-4565\(01\)00029-8](http://dx.doi.org/10.1016/S0306-4565(01)00029-8)
- [48] Everson CA, Smith CB, Sokoloff L. Effects of prolonged sleep deprivation on local rates of cerebral energy metabolism in freely moving rats. *J Neurosci* 1994; 14:6769-78; PMID:7965078
- [49] Rechtschaffen A, Bergmann BM, Everson CA, Kushida CA, Gilliland MA. Sleep deprivation in the rat: X. Integration and discussion of the findings. *Sleep* 1989; 12:68-87; PMID:2648533
- [50] Raymann RJEM, Swaab DF, Van Someren EJW. Cutaneous warming promotes sleep onset. *Am J Physiol* 2005; 288:R1589-R97
- [51] Raymann RJEM, Swaab DF, Van Someren EJW. Skin deep: cutaneous temperature determines sleep depth. *Brain* 2008; 131:500-13; PMID:18192289; <http://dx.doi.org/10.1093/brain/awm315>
- [52] Van Someren EJW. Age-Related Changes in Thermoreception and Thermoregulation. In: Masoro E, Austad S, eds. *Handbook of the Biology of Aging*. Amsterdam: Elsevier, 2011:463-78
- [53] Romeijn N, Raymann RJ, Most E, Te Lindert B, Van Der Meijden WP, Fronczek R, Gomez-Herrero G, Van Someren EJ. Sleep, vigilance, and thermosensitivity. *Pflügers Archiv Eur J Physiol* 2012; 463:169-76; <http://dx.doi.org/10.1007/s00424-011-1042-2>
- [54] Miller JC, Miller JN. *Statistics for analytical chemistry*. New York: Ellis Horwood, 1993