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SHORT REPORT

Warm ears, a red flag for sleepiness?

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Summary

Core body and skin temperatures are intimately linked to sleep and alertness. The distal-to-proximal skin temperature gradient has been described as a good physiological predictor for sleep onset. Increased ear skin temperature is often caused by increased blood flow reflected in redness, which is commonly noticed in people who are sleepy, especially anecdotally in children. Nonetheless, no prior study investigated the possible relation between sleepiness and ear skin temperature as a separate measurement. We assessed the relation between ear skin temperature and sleepiness in patients undergoing regular electroencephalographic examinations, because of suspicion of epilepsy, both without and after sleep deprivation. Subjective sleepiness was measured using the Stanford Sleepiness Scale, and objective sleepiness by determining sleep onset with electroencephalography. Distal, proximal and ear skin temperature were measured repeatedly using wireless measurement devices (iButtons). Forty-four adult patients were included. Ear skin temperature correlates weakly with distal skin temperature ($r = 0.174$, $p < 0.001$) and distal-to-proximal gradient ($r = 0.160$, $p < 0.001$), but not with proximal skin temperature ($r = -0.001$, $p = 0.975$). Ear skin temperature increased significantly in a subgroup of 13 patients, between 5 and 1 min before sleep onset ($p = 0.002$; $\eta^2 = 0.059$), even though this increase was also associated with supine posture. iButtons is a valid method to measure ear skin temperature, which appears to function partly like a distal and partly like a proximal skin temperature measurement. Change in ear skin temperature is associated with sleep onset and supine posture.

KEYWORDS
ear temperature, skin temperature, sleep onset, sleepiness

1 | INTRODUCTION

Core body and skin temperatures are intimately linked to sleep and alertness. The combination of a relatively high core body temperature and a relatively low skin temperature is associated with wakefulness (Fronczek et al., 2008), while the opposite pattern is associated with sleepiness (Kräuchi et al., 1999).

This distal-to-proximal skin temperature gradient (DPG) has been demonstrated to be one of the best physiological predictors for sleep onset (Van Someren, 2006). The change from a diurnal to a nocturnal pattern is mediated through increased perfusion of the arterio-venous anastomoses (AVAs) of the distal skin (i.e. hands and feet), facilitating heat loss and cooling of the body (Walloe, 2016). These AVAs have also been found in the nose and earlobes (Blankfield, 2006; Midttun & Sejrsen, 1996).

Anecdotally, ear redness seems to be commonly noticed in people with increased sleepiness, especially in children. Despite the fact that the relation between DPG and distal and proximal skin temperatures is extensively studied, no prior study investigated the relation between sleepiness and skin temperature of the earlobes in either children or adults as a separate measurement.

If such a relation was to exist, the measurement of ear skin temperature would be an easy and objective alternative to measuring the DPG to ascertain sleepiness in a clinical setting. Additionally, it could open up possibilities for predicting sleep onset in situations when falling asleep is highly undesirable (e.g. driver sleepiness warning systems).

To delve deeper into the relationship between increased ear skin temperature and sleepiness, we assessed ear skin temperature, sleepiness and its relation to sleep onset in patients undergoing regular electroencephalographic (EEG) examinations.

2 | METHODS

2.1 | Subjects

This study was performed at the neurophysiology department of the Leiden University Medical Centre (LUMC). All subsequent patients (age ≥ 18 years) planned for an EEG examination because of a suspicion of epilepsy were approached for inclusion. We excluded patients that used sleep medication, stimulants, ß-adrenergic antagonists or other vasoactive medication, because these influence sleepiness and blood flow. If patients underwent both a normal EEG examination and an EEG examination after sleep deprivation, measurements were performed during the EEG examination after sleep deprivation to increase the probability of sleep onset during the measurement. Patients who underwent an EEG examination after sleep deprivation were instructed to stay awake during the whole night in their own home.

The study was approved by the Medical Ethics Committee of the Leiden University Medical Center.

2.2 | Study method

During EEG preparation and approximately 5 min before EEG registration started, the Stanford Sleepiness Scale (SSS) was administered as a subjective measure of sleepiness (Hoddes et al., 1973). Skin temperature recordings were performed using eight wireless DS1921H-F5 Thermochron iButtons (van Marken Lichtenbelt et al., 2006). These iButtons have a physical range of 15.0–46.0°C, with an accuracy of ± 1°C and a resolution of 0.125°C. The iButtons were set using the OneWireViewer software (Maxim integrated products TM, San Jose) for recording measurements with 5-min intervals and applied to different parts of the body. Ear skin temperature was measured on one earlobe with the iButton taped with the smaller and more sensitive part to the front side of the earlobe that does not contain cartilage. Distal skin temperature was measured at the medial metatarsal area of the plantar sides of both feet and the thenar area of the palmar side of both hands. Proximal skin temperature was measured at the left infraclavicular area, 1 cm above the umbilicus and on the left midthigh. In the last 13 consecutive patients, who were all sleep deprived and fell asleep, we also measured skin temperature with a 1-min interval to be able to assess skin temperature dynamics before the moment of falling asleep with more appropriate resolution. Sleep-onset latency in the first 31 patients was frequently that close to the beginning of the measurement that the initial 5-min interval did not render sufficient values to be able to assess skin temperature dynamics before sleep onset. Afterwards, the DPG was calculated by subtraction of the proximal from the distal skin temperature.

During the preparation for EEG examination, iButtons were applied as described above, and an additional ear skin temperature measurement was performed using a Testo 905-T2 Compact Surface Thermometer as a gold-standard measurement, with the patient lying in the supine position at the same moment that the SSS was administered. Patients remained in the supine position during the EEG registration that took 30 min. No instruction on either trying to fall asleep or staying awake or keeping their eyes open or closed was given, but for patients undergoing an EEG recording after sleep deprivation, it can be assumed that they were aware that the purpose of sleep deprivation was to perform an EEG during sleep.

During the 30-min EEG registration, temperature was measured using the iButtons. After the EEG was performed, another measurement with the surface thermometer was performed and the iButtons were removed. All EEGs were performed during morning hours; room temperature was between 21.2°C and 22.2°C and remained constant during EEG registrations.

2.3 | Data analysis and statistics

Statistical analysis was performed using SPSS Statistics. To determine whether ear skin temperature is associated with falling asleep, the temperature before falling asleep was collected with a 1-min interval in 13 participants who all fell asleep. With these data, a general linear model for repeated-measures with Greenhouse–Geisser correction was performed for the last 5 min before sleep onset both without and with time in the supine posture as a parameter in the model. Additionally, 5-min intervals right before sleep onset and all other 5-min intervals of all patients were compared with the supine posture as a covariate using univariate ANOVA to assess the influence of supine posture on ear skin temperature change on a more extensive, but less detailed data set.

To assess the validity of the use of iButtons for ear skin temperature measurement, ear skin temperatures as measured by iButton and the surface touch temperature were compared using dependent *t*-tests and Bland–Altman plot. Using the Pearson product-moment correction coefficients, correlation of ear skin temperature with proximal and distal skin temperature and DPG and SSS was assessed.

3 | RESULTS

3.1 | Patient characteristics

In total, 44 patients who were planned to undergo an EEG registration for clinical care were included. Twenty-two of these patients underwent EEG registration after a night of sleep deprivation. Twenty-one patients fell asleep during the EEG registration (of which 18 were sleep deprived). More information on included patients can be found in Table 1 and Figure S1.

TABLE 1 Patient characteristics

Age (years)	46.1 ± 17.3
Gender	57% female
SSS at inclusion	3 (1–4)
Smoking	26% "Yes"
BMI (kg m^{-2})	25.2 ± 3.8
Room temperature (°C)	21.6 ± 0.5
Diagnosis (*n*)	Epilepsy (24); suspicion of epilepsy (4); PNES (3) Other: visual snow syndrome (3); stroke (2); CAA (2); BPPD (1); orthostatic hypotension (1); eosinophilic meningo-encephalitis (1); migraine (1); vasovagal syncope (1); no diagnosis (1)

Age, BMI and room temperature during measurements are provided as mean ± standard deviation. SSS at inclusion is described as median (interquartile range).
BMI, body mass index; BPPD, benign paroxysmal positional vertigo; CAA, cerebral amyloid angiopathy; PNES, psychogenic non-epileptic seizures; SSS, Stanford Sleepiness Scale.

3.2 | Comparison between iButtons and surface thermometer

Ear skin temperature measured with the iButtons was not significantly different from ear skin temperature as measured by the Testo 905-T2 Compact Surface Thermometer in all patients at the end of the EEG registration (32.4°C ± 2.0°C versus 32.6°C ± 2.0°C, $p = 0.374$; $n = 44$). The Bland–Altman plot showed adequate agreement between both modalities of measuring ear skin temperature (Figure S2).

3.3 | Relation between ear skin temperature and SSS, DPG, proximal and distal skin temperature

Ear skin temperature correlates significantly, but weakly, with distal temperature ($r = 0.174$; $p < 0.001$) and with DPG ($r = 0.160$; $p < 0.001$). No significant correlation was found with proximal temperature ($r = -0.001$; $p = 0.975$). Additionally, no correlation was found between instantaneous ear skin temperature and SSS scores ($r = 0.063$; $p = 0.687$), suggesting that ear skin temperature does not reflect subjective sleepiness.

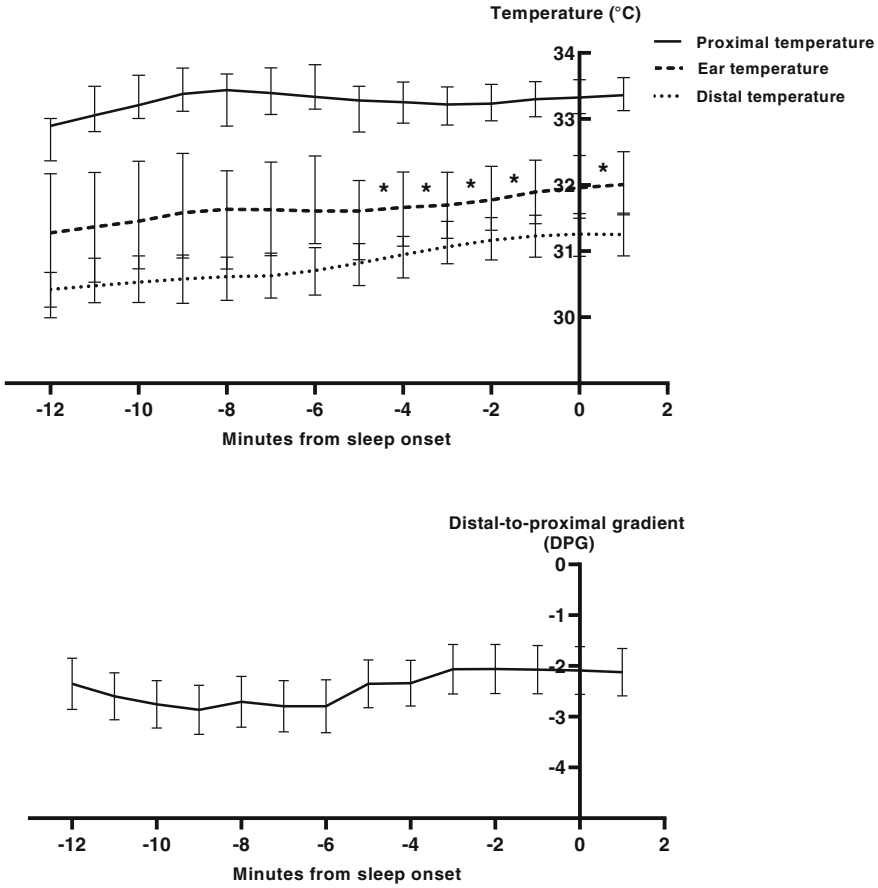

FIGURE 1 Skin temperature dynamics before sleep onset. This figure shows the data and SEM every minute before sleep onset of all patients in which skin temperature was measured with 1-min intervals ($N = 13$). More data points are available closer to sleep onset ($N = 7$ at $t = -12$ versus $N = 13$ at $t = -3$). (a) Distal, proximal and ear skin temperature of all patients before falling asleep ($t = 0$). (b) DPG before falling asleep. *$p < 0.05$; DPG, distal to proximal gradient; SEM, standard error of the mean.

TABLE 2 Temperature increase (°C) of patients ($N = 13$) before sleep onset ($t = 0$)

	Time (min) before sleep onset	−5 vs −4	−4 vs −3	−3 vs −2	−2 vs −1	−1 vs 0	0 vs 1
Ear skin temperature	Δ temperature	0.09 ± 0.04	0.10 ± 0.04	0.09 ± 0.03	0.08 ± 0.02	0.05 ± 0.02	0.08 ± 0.03
	p-value	**0.045**	**0.022**	**0.025**	**0.005**	0.104	**0.024**
Distal skin temperature	Δ temperature	0.06 ± 0.04	0.07 ± 0.05	0.07 ± 0.04	0.03 ± 0.03	0.01 ± 0.03	< 0.01 ± 0.02
	p-value	0.179	0.241	0.168	0.287	0.648	0.958
Proximal skin temperature	Δ temperature	0.06 ± 0.03	0.03 ± 0.03	0.04 ± 0.02	0.03 ± 0.02	0.03 ± 0.02	0.03 ± 0.02
	p-value	0.057	0.259	0.068	0.173	0.053	0.217
DPG	Δ temperature	< 0.01 ± 0.02	0.03 ± 0.05	0.03 ± 0.04	< 0.01 ± 0.02	−0.01 ± 0.02	−0.02 ± 0.02
	p-value	0.844	0.496	0.453	0.808	0.398	0.193

Values derived from the general linear model ± standard error of the mean. Bold values represent values below the threshold for statistical significance. DPG, distal to proximal skin temperature gradient.

3.4 | The association of ear skin temperature with sleep onset

A significant increase in ear skin temperature starting 5 min before patients fell asleep with a medium effect size was observed using the generalized linear model (Figure 1; 31.9°C ± 0.6°C versus 32.3°C ± 0.5°C; $p = 0.002$; $\eta^2 = 0.059$) that was fitted on data of the last 13 patients. This change in temperature was not significant for proximal (33.3°C ± 0.4°C versus 33.5°C ± 0.3°C; $p = 0.083$) and distal skin temperature (30.6°C ± 0.3°C versus 30.9°C ± 0.3°C; $p = 0.246$), nor for DPG (−2.7°C ± 0.5°C versus −2.7°C ± 0.5°C; $p = 0.664$), although for these skin temperature measurements the same trend was visible, especially for proximal skin temperature. Three patients who fell asleep within 3 min after EEG recording had started were excluded in this specific analysis due to lack of values 5 min and 4 min before sleep onset. However, performing the same analysis starting 3 min before sleep onset, the same significant results were found for ear skin temperature measurements ($p < 0.001$).

Between 5 min and 1 min before sleep onset, a significant increase of ear skin temperature was found every minute. These results are shown in Tables 2 and S2. No significant increases in DPG, distal or proximal skin temperature before sleep onset were found for these intervals.

Adding sleep-onset latency to the original regression model emphasized the statistical significance of the ear skin temperature change between 5 min and 1 min before sleep onset (Table S3).

However, comparing ear skin temperature change in all 5-min intervals that preceded sleep onset and all 5-min intervals that did not precede sleep onset of all patients with time since lying down as a covariate showed that for these intervals ear skin temperature was dictated mostly by supine posture rather than sleep onset (Table S4).

4 | DISCUSSION

We found a clear relation between ear skin temperature changes and sleep onset: ear skin temperature increased significantly every minute, with a stabilization at 1 min before sleep onset. When assessing 5-min intervals, time since supine posture is more strongly associated with an increase in ear skin temperature than falling asleep. This same pattern was found for DPG, albeit not significantly so, supporting previous findings that the DPG becomes less negative before sleep onset (Kräuchi et al., 2000). DPG is currently regarded as an important predictor of sleep onset (Kräuchi et al., 1999; van Marken Lichtenbelt et al., 2006). Our data suggest that ear skin temperature might be an alternative and more practical method to predict sleep onset. To measure DPG, distal and proximal skin temperatures have to be measured simultaneously. Measuring ear skin temperature is less invasive, as just one temperature measurement on the ear lobe is needed. This opens up possibilities for application in wearables outside the clinical setting, for example in driver sleepiness warning systems for professional truck drivers.

In this context, our finding that wireless temperature buttons (iButtons) were similar to ear skin measurements with a touch thermometer on two separate time points at the beginning and the end of the measurement supports the use of iButtons as a non-invasive way to measure ear skin temperature. Additionally, iButtons have the convenience of being able to make repeated measurements.

Ear skin temperature correlates with distal skin temperature and DPG. However, based on its pattern throughout the measurement, it seems to function partly like a distal and partly like a proximal skin temperature measurement, and should thus not be regarded as a surrogate for either one of those. Two studies investigated the association between DPG and vigilance instead of sleepiness using ear skin temperature as a distal skin temperature measurement (Ramautar et al., 2013; Romeijn et al., 2012). Regarding ear skin temperature to be a distal skin temperature measurement was decided on a theoretical basis, while our results argue against considering ear skin temperature to be a pure distal skin temperature measurement.

There are several limitations. Because we included patients that underwent an EEG for medical reasons, our population was very diverse, as described in Table 1. Because of this diversity we were not able to correct for factors influencing temperature management (such as age, medical history, physical activity, smoking, alcohol and caffeine

consumption), and generalizability of the findings in this sample is limited (Petrofsky et al., 2012; Priego Quesada et al., 2016; Weatherby, 1942). Regardless of this diversity, we still see a robust change in ear skin temperature associated with supine posture. Because our sample was small, future studies should standardize these characteristics to evaluate the influence of these factors and ambient temperature on ear skin temperature and its predictive value on sleep onset, and should measure skin temperature with short intervals that we were only able to do for part of the participants.

Part of the study population was measured after a night of sleep deprivation. We deliberately chose these EEGs in patients who had multiple EEGs to increase the probability of sleep onset during the measurements. Even though we are not aware of literature describing a separate effect of sleep deprivation on skin temperature other than the effect mediated by sleepiness itself, we could not exclude this possibility. Comparison of ear temperature in our patient sample did not show a significant difference between the sleep-deprived and non-sleep-deprived patient groups, even though SSS did differ significantly before the EEG registration and sleep-deprived patients fell asleep significantly more often during the EEG registration (Table S1).

Our study design does not allow for effectively disentangling the relative magnitude of the association of supine posture and that of sleep onset with ear skin temperature increase. The control population consisted of all 5-min intervals that were not preceding sleep onset. However, patients that eventually fell asleep might have been sleepy > 5 min before sleep onset. More so, even patients who did not fall asleep might have been sleepy, after being deprived of sleep the night before. If sleep onset, and thereby sleepiness, is influencing ear skin temperature, our relatively sleepy control group might have led to an underestimation of the effect of sleep onset and an overestimation of the association of ear skin temperature increase and supine posture. To disentangle the relation between supine posture, sleep onset and ear skin temperature, future studies could include non-sleepy individuals in which ear skin temperature is measured in a non-supine position. For example a position similar to the recommendations for the maintenance of wakefulness tests (Krahn et al., 2021). In this way, the association of supine posture and ear skin temperature increase could be separated from the association of sleepiness and ear skin temperature increase.

We initiated this study based upon observations primarily made in children. Children have a slightly different temperature regulation pattern in comparison with adults, with a higher skin temperature. This is mainly due to their higher surface-area-to mass ratio and higher metabolic expense. As a result, children dispose of heat via dry heat exchange mechanisms, with a circulatory shift to peripheral blood flow (Falk, 1998). It is likely that the changes in ear skin temperature are more pronounced in children. For ethical purposes we decided to initiate the assessment of ear skin temperature in an adult population; however, future studies should focus on evaluating ear skin temperature in children.

In conclusion, this study shows that ear skin temperature can be regarded as a measurement that partly functions like a distal and partly like a proximal skin temperature measurement, and increases before sleep onset and with supine posture. The diversity of our patient population urges replication of our results in more extensive and homogeneous patient populations.

AUTHOR CONTRIBUTIONS

Study design: Mink S. Schinkelshoek, Rolf Fronczek, Martijn R. Tannemaat and Gert J. Lammers. Data entry: Mink S. Schinkelshoek, Anke F. J. de Boer and Kay de Wit. Data analysis: Mink S. Schinkelshoek, Anke F. J. de Boer and Kay de Wit. Writing and reviewing the manuscript: Mink S. Schinkelshoek, Rolf Fronczek, Martijn R. Tannemaat and Gert J. Lammers.

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CONFLICTS OF INTEREST

No (non-) financial conflict of interest regarding the contents of this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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