LOCALISED TEMPERATURE PERCEPTION IN HEALTHY ADULTS

Jérôme Foussier
Medical Information Technology, RWTH Aachen, Pauwelsstr. 20, 52074 Aachen, Germany

Jennifer Caffarel, Jürgen Te Vrugt
Philips Technologie GmbH Forschungslaboratorien Aachen, Weißhausstr. 2, 52066 Aachen, Germany

Steffen Leonhardt
Medical Information Technology, RWTH Aachen, Pauwelsstr. 20, 52074 Aachen, Germany

Keywords: Local temperature perception, Peltier element, Temperature sensation rate.

Abstract: This paper presents a testing procedure for local temperature perception with a following evaluation of the acquired information. Relative temperature changes had to be noticed by the subjects. To apply a temperature effect a peltier element arrangement, permitting to cool down and heat up with one element, has been utilized. First results show good correlation with a warmth sensation scale, although highly subjective parameters have been interpreted. The error rate in detecting small temperature changes is higher than for larger changes, except for very high changes, which caused temperature misperceptions.

1 BACKGROUND

In some therapies the effect of cooling and heating is used to treat illnesses (e.g. cryotherapy in pain management, taking cold showers after a sauna session or in photo thermal therapy). Another treatment shows that cooling down fresh burn wounds to a certain temperature improves healing and limits tissue damage (Venter, T., Karpelowsky, J., Rode, H., 2000). The use of superficial heat results in higher tendons and ligament flexibility, muscle spasm reduction, pain alleviation, blood flow elevation or even boosts the metabolism (Kaul M. P.; Herring S. A., 1994).

In therapies the affected areas sometimes are smaller so that an overall cooling or heating would not make more sense than a local temperature change. In general the human body is a bad temperature measurement device and the temperature sensation increases while stimulating bigger areas (Parsons, K. C., 2003). It is possible to believe there is a change to hot temperatures even when temperature is decreasing. This can be shown by the "grill effect" (Craig, A. D., 2002) for example, where two metal plates, one hotter than the other, both over skin temperature, are placed close-by, and the person perceives a hot sensation. The first grill illusion was created by interlaced warm and cold stimuli at 40°C and 20°C by Thunberg in 1896 (Defrin, R. et al., 2002). Reducing the area reduces the complexity of the hardware and the needed power. The stimulation would be more precise.

Mostly, larger areas of the body are heated up or cooled down, but what about cooling and heating local spots and can even small temperature changes (e.g. ±1°C) be detected on a small area of skin? If not, how big should the temperature step should at least be to notice a change and is there a difference between hot to cold change or cold to hot? This paper will describe a testing procedure to answer those questions.

2 TECHNICAL DESCRIPTION

In general the designed system handles temperature ranges from 17°C to 40°C in a controlled way,

Foussier J., Caffarel J., Te Vrugt J. and Leonhardt S..
LOCALISED TEMPERATURE PERCEPTION IN HEALTHY ADULTS.
DOI: 10.5220/0003154801990203
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2011), pages 199-203
ISBN: 978-989-8425-37-9

regarding the safe temperature ranges applied to the skin, where temperatures below 15°C become "slightly painful" as described in a study to develop a European safety standard for touching cold surfaces (Malchaire, J., et al., 2002). An application of more than 45°C, close to burn threshold, evokes pain (Parsons, K. C., 2003).

2.1 Cooling and Heating Device

The cooling and heating device consists of a 2.5cm high built up peltier element arrangement (Figure 1). Both sides of the element are glued on 3x3cm large aluminum plates, of course thermally isolated each other. Similar arrangements can also be found in other construction, e.g. for rating the performance of a peltier element. The bottom "cold" side is applied to the skin. On the "hot" side, a ribbed heat sink with a top-mounted fan ensures the dissipation of heat, which is provoked by the peltier element itself, due to the general poor energy efficiency of about 50-60%. By inverting the flow direction of the electrical current, it is possible to switch the "hot" and the "cold" side of the peltier element, hence allowing cooling and heating of the skin with one single element.

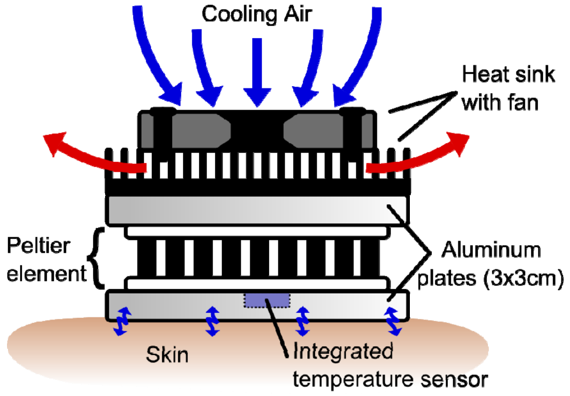

Figure 1: Schematic view of the assembly.

2.2 Temperature Controller

A microcontroller controls the temperature on the skin side by permanently evaluating the embedded and calibrated temperature sensor. Using peltier elements with alternating voltages or currents means a further loss in efficiency, because the heat transfer direction is inverted during the negative peaks of the signal. This is the reason why a microcontroller-regulated DC controller has been built to prevent the negative effect and to keep the temperature constant at the desired value. It also allows temperature change rates on the skin in the order of 1-3°C/s.

The temperature controller can be managed via a personal computer and adequate software. With a graphical user interface (GUI), the investigator is able to set the output temperature either manually or automatically with a predefined list. A graph displays real-time measured temperature values to be able to control the correct functioning of the hardware. In addition, an automatic program can be started, which switches between two fixed temperatures for a defined duration.

3 TEMPERATURE PERCEPTION TEST

For the test the cooling and heating device was attached to the forearm (see Figure 2).

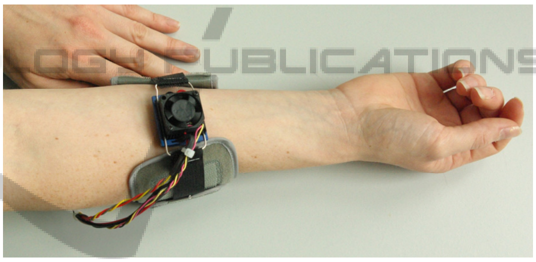

Figure 2: Peltier element with fixing cuff applied to the forearm.

This location is easily accessible, the fat layer is not very thick and the thin skin is sensitive. In addition possible hairiness of the person does not affect the application.

Table 1: Overview of all subjects (values are in the format: mean (standard deviation)).

	Overall	Female	Male
Number	11	4	7
Over 30 yrs.	6	2	4
Under 30 yrs.	5	2	3
Age	36.8 (10.4)	33.75 (10.1)	38.6 (10.5)
$T_{neutral}$ [°C]	33.1 (2.1)	32.3 (0.5)	33.6 (2.6)

Table 1 gives an overview of all the subjects who attended the test, where $T_{neutral}$ gives the individual perception of the neutral sensed temperature of the applied element. As not only the temperature but also the kind of applied material and the contact pressure play a role in temperature perception, the neutral temperature is not necessarily equal to the real skin temperature of the person. This is due to different contact coefficients and different resulting contact temperatures t_k (Lutz, P., 2002).

$$t_k = \frac{b_1 \cdot t_1 + b_2 \cdot t_2}{b_1 + b_2} \tag{1}$$

where b_1 and b_2 are the contact coefficients in $Ws^{0.5}m^{-2}{}^{\circ}C^{-1}$, t_1 and t_2 the contact temperatures of the two materials in °C. Example values for wood, steel and skin contact coefficients are $b_{wood} \approx 400$, $b_{steel} \approx 14000$ and $b_{skin} \approx 1000$. At room temperature (22°C) the contact temperatures between skin (34°C) and steel/wood are respectively 23°C and 31.5°C. This shows that wood feels warmer than steel at equal object temperatures. To feel the aluminum plate as neutral it consequently has to be heated up and kept at a constant temperature. It is important that the person has to get used to the whole element, before the test can be started to avoid any bias sensation. Afterwards the test can be initiated:

The whole test procedure consists of five different subtests:

1. Determining the neutral sensed temperature $T_{neutral}$ of the peltier element
2. Varying the temperature slightly (max. ±Δ3°C) around $T_{neutral}$ randomly
3. Varying the temperature in bigger random steps (max. –Δ22°C and +Δ6°C to $T_{neutral}$)
4. Cycling in time steps of 20s between two fixed temperatures (e.g. 18°C ↔ 33°C)
5. Same as 2.

In case of an extreme discomfort, the subjects were instructed how to remove the element from the fixation rapidly and by themselves. The subjects were asked to describe every change they noticed and to rate their perception (e.g. spatial, temperature and comfort), without knowing the actual temperature value. The investigators wrote down every remark during the test while the computer displayed and recorded the temperature measurement values. None of the persons sensed an extreme discomfort with the applied temperatures. Each subtest started and ended with the neutral temperature to avoid any accommodation or greater loss in sensitivity. The total duration of the test was approximately 30 minutes for each person.

4 RESULTS AND DISCUSSION

Mainly there are two possibilities to interpret the obtained information. The first one would be to determine the difference between two temperature set points, the second the difference between the neutral temperature of the person and the set point. For a start the focus was set on the first possibility, by gathering all the occurrences of temperature steps from the test (410 in total). To obtain a representative graphical evaluation, five temperature steps have been merged into one group and normalised to the total number of occurrences in this group.

Figure 3 shows the result of all persons. "🟨 0" means that the person did not detect a change or was unsure, "🟩 ==" denotes a correct (e.g. sensation of warming for an increase in temperature) and "🟥 !=" an incorrect sensed temperature change. Distinguishing between female/male persons or under/over 30 years old persons did not produce significant differences in results. The absolute sums of the occurrences in the seven ranges are as follows: [75, 26, 51, 119, 42, 31, 66]. Greater temperature steps are better distinguishable (>70%) than smaller steps and uncertainties or incorrect answers are almost insignificant. The overall average percentage of incorrect answers is less than 15%.

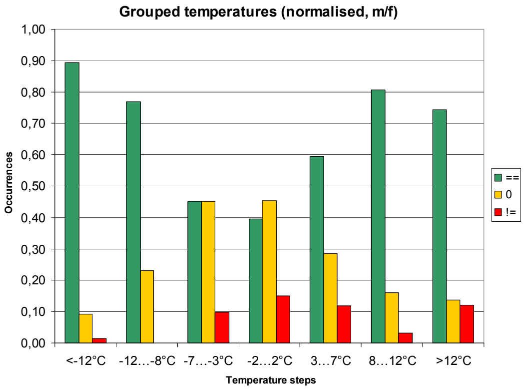

Figure 3: Overall evaluation of perceived temperature steps (normalised for male and female).

The above described test procedure allows interpreting the average temperature sensation over the whole testing time. As subtest 2 and subtest 5 use equal temperature steps (see chapter 3), one just performed at the beginning, the other at the end of the whole test, it is possible to give a trend on how the sensitivity altered, especially for small changes around the neutral temperature (±Δ3°C). The results for this are given in Table 2, which gives a separate view on all, male and female persons, over and under 30 years old persons. It is clear, that sensing performance decreases. The subjects found it harder to detect the small temperature steps after having performed the two subtests with bigger temperature steps before. If they had guessed for the temperature changes, statistically the "==" and the "!=" data would have changed similarly. In fact only the "==" degraded significantly and the persons either tended to say nothing or were confused by the sensation (reconstructed on the basis of the acquisition protocol) which leads in higher values for the "0". Striking points are the values for female persons in the "!=" section, where the wrong perception of temperatures increased instead of falling compared to the other subjects. This could be explained by the strong decrease in the "==" and the relative low increase in the "0" section compared to the male subjects. The incertitude for sensing a small temperature change in this test is therefore higher for female than for male persons.

Table 2: Comparison between the same subtests 2 and 5.

		Subtest 2	Subtest 5	Difference
==	All	44.7%	37.8%	-6.9%
	Female	45.2%	35.5%	-9.7%
	Male	44.4%	39.2%	-5.2%
	> 30 years	37%	31.1%	-5.9%
	< 30 years	53.8%	45.9%	-7.9%
!=	All	14.1%	13.4%	-0.7%
	Female	9.7%	12.9%	3.2%
	Male	16.7%	13.7%	-3%
	> 30 years	15.2%	13.3%	-1.9%
	< 30 years	12.8%	13.5%	0.7%
0	All	41.2%	48.8%	7.6%
	Female	45.2%	51.6%	6.4%
	Male	38.9%	47.1%	8.2%
	> 30 years	47.8%	55.6%	7.8%
	< 30 years	33.3%	40.5%	7.2%

Based on two existing scales of warmth sensation, the Bedford comfort scale and the ASHRAE sensation scale (Parsons, K. C., 2003), it is possible to classify words like "cool", "warm" and "neutral" according to Table 3 (Parsons, K. C., 2003).

Table 3: Scales of warmth sensation.

Scale	Bedford comfort scale	ASHRAE sensation scale
7	Much too warm	Hot
6	Warm	Warm
5	Comfortably warm	Slightly warm
4	Comfortable	Neutral
3	Comfortably cool	Slightly cool
2	Too cool	Cool
1	Much too cool	Cold

Both combined with the delivered comments (a total count of 341) of the tested persons, noted in the acquisition protocol, and related to their neutral perceived temperature, it is possible, even though not always evident, to generate an intensity map of the sensation (Figure 4). This is a potential alternative to interpret the obtained data. In the graph the temperature difference to the neutral temperature is ranged from -22°C to +7°C on the abscissa, where 0°C represents the neutral temperature. The intensities of three temperatures have been summed up, followed by a normalisation to 1. The warmth scale is applied to the ordinate, ranging from 1=cold to 7=hot.

Except for some outliers, especially around -20°C, caused by a misperception of a big temperature step (can be seen for "■ !=" in Figure 3), the linear trend (dotted line) is clearly noticeable and encourages the use of the sensation scale as indicator, even if it could seem that the use of words should deliver very vague information. It is amazing that persons around the neutral temperature (±Δ3°C) mostly say that it is comfortable, but cannot notice small changes reliably (see Table 2).

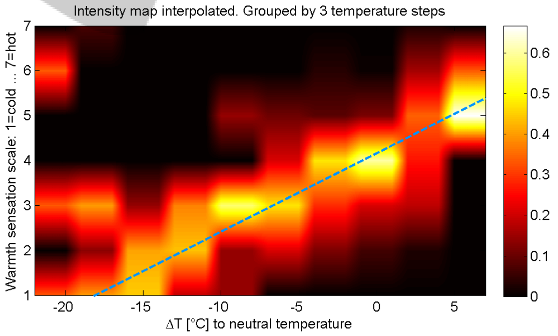

Figure 4: Temperature sensation map, using a combination of the Bedford comfort and the ASHRAE sensation scales.

In further work the post-analysis of the test by another person should be replaced by a scale, where the persons can enter themselves their perception in the range of 1-7 (cold-hot). Integrated into a separate input mask, such as a touch sensitive display, the data acquisition could be automated as far as possible thus reducing interpretation errors and the amount of outliers which would give an even clearer trend in the temperature sensation intensity map. Also the effect of placebo could be investigated by showing the persons "wrong" temperature values and therefore subconsciously influencing their temperature perception.

The placement of the element shows one big disadvantage: the exposure of the arm to the ambient temperature could lead to a centralization of the whole body resulting in colder extremities and a possible lower temperature sensation. Answer to this issue could be to cover the skin around the element with a piece of cloth.

To conclude the discussion the results show that small temperature changes (±Δ2°C in Figure 3) on a small surface cannot be sensed reliably. For reliabilities greater than 60% a temperature step of at least ±Δ8°C is needed. A major difference between a hot to cold and a cold to hot change could not be definitively found in this testing, thus needing more investigation on this open question.

ACKNOWLEDGEMENTS

Research was supervised by Prof. Dr.-Ing. Dr. med. S. Leonhardt, RWTH Aachen University in Aachen and has been supported by Dr. J. Caffarel and Dr. J. te Vrugt of the Philips Research Aachen.

REFERENCES

Venter, T., Karpelowsky, J., Rode, H., 2000. Cooling of the burn wound: The ideal temperature of the coolant. In Burns

Kaul M. P.; Herring S. A., 1994. Superficial Heat and Cold: How to Maximise the Benefits. *In The Physician and Sportsmedicine.*

Parsons, K. C., 2003. Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort and performance, *2nd edition*

Craig, A. D., 2002. How do you feel? Interoception: the sense of the physiological condition of the body. *In Nature Reviews Neuroscience 3.*

Defrin, R. et al., 2002. Sensory determinants of thermal pain. In Brain

Malchaire, J., et al., 2002. Temperature Limit Values for Gripping Cold Surfaces, *In The Annals of Occupational Hygiene.*

Lutz, P., 2002. Lehrbuch der Bauphysik, Vieweg+Teubner Verlag, *5th edition*