Skin temperature as an indicator of thermal environment's influence on cognitive response

E. Quelhas Costa, J. Santos Baptista and Jorge Carvalho
FEUP

Abstract
Skin temperature is controlled by the sympathetic nerve activity that reflects the flow of information processed in the brain, being by that, appointed as an effective indicator in objectively evaluating human behavior. Even when the entire skin surface is exposed to a constant ambient temperature, skin temperature varies considerably on the different areas. It is intended in this article to determine, by a literature review, how the skin temperature is an effective and objective physiological indicator in providing a tool to assess the level of awareness and thermal environment influence on cognitive response in sedentary activity. For this purpose a search was carried on in different databases such as Pub Med, Web Science and Scientific Journals. According to the objective of this paper, only work related to humans was considered and the priority was given to studies with ethics committee approval or, at least, informed consent. Many schemes have been proposed for varying the number of measurement points and the respective weighting factors. However, mapping the skin temperature of people who perform low metabolic level tasks in different thermal conditions has not been investigated sufficiently. So, there is a huge amount of activities and situations in which people shall undergo these conditions, ranging from office activity up to operators at nuclear power plants.

Keywords: Thermal Environment; Skin Temperature, Thermal Sensation, Heat, Sedentary activity

1. INTRODUCTION
The skin is the boundary between inner body and external environment and it is the largest human body organ. The skin controls the flow of heat and moisture between the body and the surrounding environment; protects the body from the sun's rays and helps to keep a constant internal body temperature (around 37°C). Skin temperature also depends on climatic factors such as humidity, air temperature, wind chill and time of exposure to a particular environment. The temperature of the skin also changes over its own surface, especially in cold environmental conditions. Arens and H.Z.(2006) states that the normal average skin temperature (t_{skm}) is about 33°C (91°F) which can be referred as its "set point". Faced with changing external environmental conditions, skin regions that contain more blood vessels, more quickly return to the "set point" than regions with fewer blood vessels (Arens E. and H.Z. 2006). Pilcher (2002) refers in its meta-analysis that the effect of hot and cold temperature exposure have a negative impact on performance on an extensive range of cognitive-related tasks. Furthermore, the time of temperature exposure prior to the task onset, the type of task and the duration of the task had different effects on work performance. Faced with this problem, the aim of this paper is to determine the extent in which the skin temperature is an effective and objective physiological indicator to provide a tool to assess the level of awareness and thermal environment influence on cognitive response in sedentary activity.

2. MATERIALS AND METHOD
This study was based on searching in different databases such as Pub Med, Web Science and Scientific Journals, keyword combinations such as: "Skin temperature and heat, Skin temperature & thermal environment, Temperature forehead & sedentary activity, Skin temperature & cognitive performance, Skin Temperature & Thermal Sensation, which allowed to identify, select and analyse relevant documents in this field. Only works related to humans were considered. Priority was given to studies with ethics committee approval or, at least, informed consent.

3. SKIN TEMPERATURE
3.1 Skin and core body temperature
Body temperature is a physiological parameter of great importance both in clinical and research applications. However, this parameter changes with measurement's location point and environmental temperature. It can be measured internally, corresponding in this case to "core temperature" or can be measured more superficially (skin; axillary, tympanic, oral) and in this case being more influenced by the ambient temperature and less reproductive than the core temperature (Ribeiro, 2010).Body temperature can be measured in degrees Celsius (°C) International metric system (freezing and boiling values equal respectively to 0°C and 100°C) or in degrees Fahrenheit (°F) used in USA (freezing and boiling values equal respectively to 32ºF and 212ºF). The skin controls its heat and humidity through a range of metabolic adjustments. The lower value corresponds to basal metabolism (a seated person resting) that can grow up until a maximum value (a person under maximum effort). If a person is in a hot room and skin temperature is lower than the air temperature, the temperature of the skin increases. The opposite is also true, i.e. in a cold room, the temperature of a hot skin, will decrease. Outdoors, either the wind or the sun strongly affects the loss or gain of heat by convection or radiation respectively. These processes act asymmetrically and heterogeneously on the body, affecting some parts more than others. Skin temperature depends on thermal exchanges by conduction, convection, radiation, evaporation,

changes in blood flow and arterial blood temperature which reaches each zone of the body. The heat changes from the body are made precisely by these thermal exchanges. When air temperature is close to skin temperature around (31-33 ° C) the heat losses from convection ceases and, under these conditions, the body becomes highly and almost totally dependent on the evaporative cooling for heat dissipation (Baker, 1954). The skin contains numerous sensorial receptors which receive information from the external environment. These receptors are related to at least five different sensations: pain, heat, cold, touch and pressure. The receptors that detect skin temperature are called thermoreceptors. These receptors respond directly to the skin temperature. Besides participating in thermoregulatory control, they affect the thermal sensation of a person and consequently comfort (Arens E. & H.Z., 2006).

3.2 Some methods and equipments to measure skin temperature

To measure the skin temperature two situations should be considered: the local temperature measured at a specific point on skin surface, representative of a limited area and the mean skin temperature estimated by weighting the measured temperatures in different locations. According to the ISO9886 standard:1992, skin temperature is a physiological parameter that is an important criterion to thermal characterization of the human body. Different schemes have been proposed for varying the number of measurement points and the respective weighting factors. There are many devices used to perform skin temperature measurements. The American company VitalSense ® produces a skin electrode, which provides real-time information, (Wireless Temperature Dermal Patch) which is hypoallergenic, waterproof and easy to use. Other systems exist, such as the system Cadillac ThermoSENSOR produced in Singapore and functions similarly, with a sensitivity of 0.2°C and monitor bioPLUX with precision temperature sensors Plux between 0.05-0.1°C produced in Portugal, which were designed for applications involving temperature readings continuous or intermittent in a range between 0 and 50ºC. The higher the temperature variation the greater the number of points needed to get a representative sample. When it comes to warm ambient temperatures, the temperature of the skin is more homogeneous due to vasodilatation and in this case, fewer points are needed to evaluate reliably the skin temperature. On the other hand, more points are needed in cold environments where the temperature of the skin due to vasoconstriction is more heterogeneous (Parsons, 2003).

3.3. Skin temperature the thermal environment and mental performance.

Yao, Y., Lian, Z., Liu, W., and Shen, Q. (2008) conducted a study aiming at investigating the influence of the thermal environment on the skin temperature and its relation to thermal comfort. For this they conducted trials in a climatic chamber at four different temperatures (21ºC, 24ºC, 26ºC and 29°C) air velocity around (0.05 ± 0.01 m.s^{-1}) and air humidity to about ($60 \pm 5\%$). There are various methods of skin temperature calculation. Those methods are generally classified into two categories:

1. those using weighting factors according to the skin region's area of each measurement,
2. those using the same weighting factor for all measurement locations.

Nobuko Hashiguchi, Y. F., and Yutaka Tochihara. (2009) in order to investigate the effects of thermal environment on mental performance in both sexes in different temperature, measured the skin temperature in twelve body points: chest, forehead, back, abdomen, forearm, back of the hand, thigh, anterior and posterior, anterior and posterior neck, instep. They used a climate chamber, where volunteers were exposed to four temperatures (16°C, 19°C, 22°C and 25°C). The volunteers waited at least twenty minutes sitting in a room at a temperature of 25°C and 50% HR humidity. They used two computers to perform the task during exposure to different temperatures. As a result, they found skin temperature differences between the upper and lower body, and more significant differences in women than in men. This study also demonstrated that lowering the temperature of the skin from the thigh to the female elements was greater than for the male elements and this decrease in skin temperature had a significant relationship with the thermal comfort. It was also found that the higher the temperature of the skin of the upper body, the higher the internal temperature. Skin temperature variation is totally different when environmental temperature is hot or cold (Arens E., & H.Z. 2006). Table 1 describes the skin temperature distribution in three conditions: neutral, hot and cold, from studies by Center for the Built Environment, University of California, Berkeley UB / Olesom and Fanger, adapted (Arens E. & H.Z. 2006).

According to the results shown in Table 1 in the dates by Arens E. & H.Z (2006, it can be seen that in a cold environment, skin temperature varied between a minimum temperature of 21.1ºC in the left finger and a maximum temperature of 34.5ºC in neck / back. In this type of environment, it was found that the temperature of the neck is high. In hot environment it has been found that skin temperature is more uniformly distributed with a little variation of 2,7°C. Other authors (Costa et al, 2013) had the same results; they found that hot skin temperature is more stable, with a variation of 2,5ºC. They also found greater stability between the different body parts at high temperatures, the results clearly pointing to the existence of a distinct acclimation when it comes to hot or cold environments. It is also important to note that both skin temperature and thermal sensation seem to reach a constant level within about 20 min (Nagano, K., Takaki, A., Hirakawa, M., & Tochihara, Y. 2005). Other studies have pointed out that the temperature at the tip of the nose is possibly effective to evaluate the mental performance (Mizuno, T., Nomura, S., Nozawa, A., Asano, H., & Ide, F, 2009); (Kataoka, H., Kano, H., Yoshida, H., Saijo, A., Yasuda, M., & Osumi, M., 1998); (Nozawa & Tacaño, 2009); (Nishimura, Murai, & Hayashi, 2011) among others. Kataoka et al (1998) investigated the relationship between stressful task and skin temperature, which demonstrated a high correlation between the stress and the temperature of the forehead and nose skin in a sedentary activity. A year before Genno, H., Saijo, A., Yoshida, H., Suzuki, R., & Osumi, M. (1997) proposed a method to automatically measure the temperature of the facial skin, this author stated that the measurement of facial skin temperature is an effective way to objectively evaluate sensations.

Table 1 Local Skin temperature (ºC) distribution in different environmental conditions

Place	Neutral conditions		Cold Conditions		Hot Conditions	
	UC Berkeley* with thin clothes	Olesom & Fanger usual clothing office	22ºC Arens E. & H.Z, (2006)	20ºC 60%Hr Costa et al. (2013)	30ºC Arens E. & H.Z, (2006)	32ºC 60%Hr Costa et al. (2013)
Forehead	35,8	34,2	30,7	31,9	36,5	35,5
Face	35,2		27,7	-	36,3	-
Neck / Front	35,8		33,5	29,3	36,8	35,9
Neck / Back	35,4		34,5	-	36,1	-
Chest	35,1	34,5	30,9	33,6	36,1	35,3
Back	35,3	34,4	32,4	32,4	36,3	35,9
Abodmen	35,3	34,9	28,7	33,3	36,2	35,9
Arms	34,2	33,5	24,7	32,9	36,4	35,3
Forearm	34,6	32,7	27,3	28,1	36,1	35,1
Hand	34,4	33,5	23,1	26,4	36	34,8
Left Finger	35,3		21,1	-	36,7	-
Thigh	34,3	33,7	27	28,8	35,6	33,4
Shin	32,9	32,6	26,5	26,9	34,4	33,8
Calf	32,7	32,2	24,3	28,1	34,1	33,7
Foot	33,3	32,2	21,4	27,6	36,4	34,7

Adapted from. Arens E. & H.Z, (2006) and Costa et al. (2013)
*Center for the Built Environment, University of California, Berkeley

4. CONCLUSIONS

According to the articles analyzed, it is already known that the skin mean temperature (t_{skm}) has a good correlation with the feeling of comfort. However, there is still concern about the correlation between the average temperature and other indexes. After this survey and in order to verify to what extent the temperature of the skin is an effective indicator to assess the influence of the thermal environment on the cognitive response in sedentary activity, were found some points that could lead to such information and one of them will be in the face. Other authors suggest that there is no correlation and direct connection between the skin temperature and performance.

5. REFERENCES

Arens, E. and H. Zhang 2006. The Skin's Role in Human Thermoregulation and Comfort. Thermal and Moisture Transport in Fibrous Materials, eds N. Pan and P. Gibson, Woodhead Publishing Ltd, pp 560-602.

Barker;, L.M., & Taylor, W.M. (1954). The relationship under stress between changes in skin temperature, electrical skin resistance, and pulse rate. Journal of Experimental Psychology, 48 (Nº5).

Costa, E.Q.; Couto, D.; Carvalho, J.; Costa, J.T.; Diogo, MT.; Baptista, J.S. (2013). Ambiente Térmico, aclimatação e temperatura da pele numa atividade sedentária – Resultados preliminares. *in* RICOT pp. 148-154 .

Genno, H., Saijo, A., Yoshida, H., Suzuki, R., & Osumi, M. (1997). Non-contact method for measuring facial skin temperature. Int. J. of Ind. Ergonomics, 19(2), 147-159. doi: http://dx.doi.org/10.1016/S0169-8141(96)00010-8

Kataoka, H., Kano, H., Yoshida, H., Saijo, A., Yasuda, M., & Osumi, M. (1998, 29 Oct-1 Nov 1998). Development of a skin temperature measuring system for non-contact stress evaluation. Paper presented at the Engineering in Medicine and Biology Society, 1998. Proceedings of the 20th Annual International Conference

Mizuno, T., Nomura, S., Nozawa, A., Asano, H., & Ide, F. (2009). Evaluation of Effect of the Mental Work and Simple Work by the Nasal Skin Temperature. ICROS-SICE International Joint Conference 2009.

Nagano, K., Takaki, A., Hirakawa, M., & Tochihara, Y. (2005). Effects of ambient temperature steps on thermal comfort requirements. Int J Biometeorol, 50(1), 33-39. doi: 10.1007/s00484-005-0265-3

Nishimura, N., Murai, K., & Hayashi, Y. (2011). Basic Study of a Mental Workload for Students´s Simulator Training Using Herat Rate Variability, Salivary Amylase Activity and Facial Temperature. Proc. of the 2011 6th International Conference on System of Systems Engineering, Albuquerque, New Mexico, Usa.

Nobuko Hashiguchi, Y. F., Yutaka Tochihara. (2009, August 22). Gender differences in thermal comfort and mental performance at different vertical air temperatures. Eur J Appl Physiol (2010) 109, 41-48.

Nozawa, A., & Tacano, M. (2009). Correlation analysis on alpha attenuation and nasal skin temperature. Journal of Statistical Mechanics: Theory and Experiment, 01.

Olesen B W and Fanger P O (1973), 'The skin temperature distribution for resting man in comfort', Arch. Sci. Physiology, 27, A385–A393.

Parsons, K. C. (2003). Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance (2nd ed.). London: Taylor & Francis.

Pilcher, J. J., Nadler, E., & Busch, C. (2002). Effects of hot and cold temperature exposure on performance: a meta-analytic review. Ergonomics, 45(10), 682-698. doi: 10.1080/00140130210158419

Ribeiro, B. (2010). Calor, Fadiga e Hidratação (1 ed., Vol. 1, pp. 555).

Yao, Y., Lian, Z., Liu, W., & Shen, Q. (2008). Experimental study on physiological responses and thermal comfort under various ambient temperatures. [Comparative Study Research Support, Non-U.S. Gov't]. Physiology Behavior, 93(1-2), 310-321. doi: 10.1016/j.physbeh.2007.09.012