Ambulatory long-term monitoring of brain temperature

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Abstract — This paper aims at presenting the first results of long-term monitoring of brain temperature using a non-invasive ambulatory device, the Brain and Core Thermometer (BCT), whose operating principle relies on the zero-heat-flow method.

The experiment presented in this paper is part of the study "Monitoring Human Circadian Physiology through Real-Time State Estimation" led by the Centre for Study and Treatment of Circadian Rhythms, Douglas Mental Health University Institute in Montreal, Canada. The main purpose of this study is the development of new methods for circadian phase monitoring in field operations. The results are for two subjects monitored for about 30 consecutive hours.

BCT measurements are compared with the rectal temperature using the Bland-Altman method. The bias of the BCT sensor was -0.029 °C, with 95 % limits of agreement at −0.38 and +0.35 °C. These results are promising, making the BCT, a suitable device for circadian rhythm studies.

Index terms - Biomedical sensors

I. INTRODUCTION

There is a growing need for ambulatory, reliable, comfortable and acceptable devices for long-term physiological monitoring. The recent and increasing availability and appeal of wireless wearables has been accelerating the design and development of ambulatory sensors [1].

At the moment, very few devices enable the ambulatory and non-invasive reliable monitoring of core body temperature (CBT). Indeed, the assessment of CBT from the skin is complex, as skin temperature must change in order to maintain the CBT at about 37 °C. Although non-invasive measurements of deep body temperature exist, such as NMR spectroscopy, microwave radiometry [2], near infrared spectroscopy or ultra-sound thermometry, very few devices work under ambulatory conditions.

This paper presents the first results obtained with the ambulatory Brain and Core Thermometer sensor that we have compared with a standard rectal temperature probe. The non-ambulatory version of the BCT has been previously validated against a rectal temperature sensor [3, 4]. It was reported that BCT values were lower than core temperature values by an average of 0.15 ± 0.08 °C. Maximal cross correlation coefficients over all subjects were close to zero hour lag (r_{max}: - 6 ± 33 min).

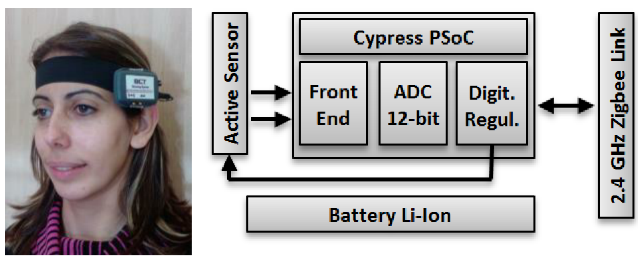
II. MATERIALS AND METHODS

II.1. Brain and Core Thermometer

The BCT is based on the zero-heat-flow principle, mainly developed by Fox et al. [5]. The sensor is composed of an insulation layer, a heating element and a thermal sensitive element. Heat losses are limited thanks to the insulation and prevented using the heating element until there is no heat flux across the sensor. When the heat flux across the sensor is zero, the surface temperature is the same as the deep temperature. This is thus measured by the thermal sensitive element within the sensor. The sensor was calibrated and tested using several physical models and phantoms and found to have a precision of ± 1/10 °C. The threshold of sensitivity is small enough to detect 1/1000 °C changes.

The sensor is attached to the temple with an elastic band (Figure 1a).

The architecture of the BCT device is based on a Programmable System on Chip from Cypress (Figure 1b). The power consumption of the system is about 45 mA at 3.7 V. The 1200 mAh battery enables the operation of the system during 24 hours before recharging. The sampling frequency of the temperature measurement is 1 Hz.



(a) (b)

Figure 1: (a) The BCT device located on the temple – The electronic part can be attached to the elastic band or worn elsewhere. (b) Block diagram of the BCT device

The BCT temperature was compared to the rectal one, as rectal temperature is a well-recognized surrogate measurement of CBT. Rectal temperature was measured by an YSI-401 temperature probe (Yellow Springs International) except during bowel movements. The probe was calibrated using instruments with an accuracy of ± 0.03 °C.

II.2. **Protocol**

The experiments took place at the Centre for Study and Treatment of Circadian Rhythms, Douglas Mental Health University Institute, Montreal (REB protocol number: 03/24). Measurements presented in this paper were recorded during a 30 h constant routine protocol in which the subject was kept awake in a time isolation room in order to remove the masking effect of sleep, activity and feeding on the output rhythms of the circadian system. Environmental temperature was maintained at 23.5 ± 2.0 °C. The subjects, healthy woman and man aged respectively 23.85 and 29.12 years, were specifically prepared for this experiment.
The comparison between BCT and core temperature was performed through the Bland-Altman approach [6].

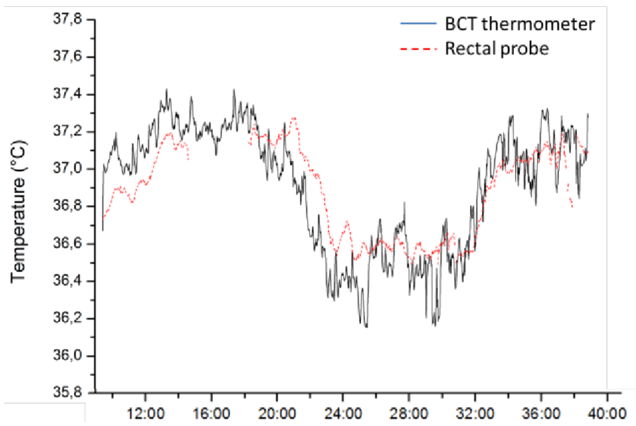


Figure 2: BCT and rectal temperature measurements recorded during 30 consecutive hours – Subject 1

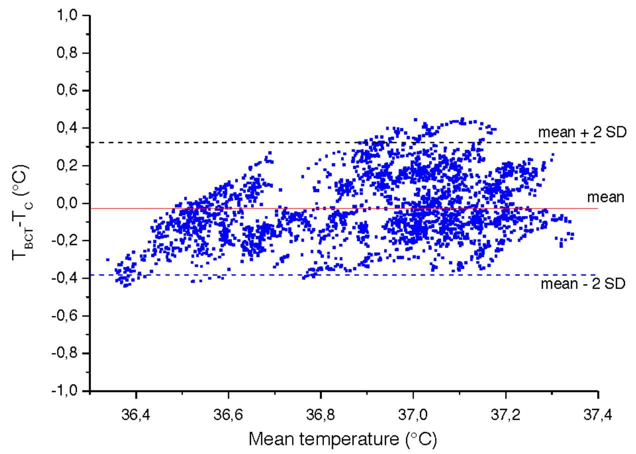


Figure 3: Bland-Altman diagram (N = 2739) - BCT sensor bias equal to -0.029 °C, with 95 % limits of agreement at −0.38 and +0.35 °C

III. **RESULTS**

Figure 2 illustrates the BCT and rectal temperatures for subject 1 for 30 consecutive hours. The rectal temperature was stopped from 2.30 pm to 6 pm due to technical problems. Both signals vary in the same way, the circadian rhythm of the core temperature is observable: the core temperature decreases from 8 pm, it is stable during the night and increases from 6 am in the morning. The BCT signal has larger amplitude variations than the rectal one as the rectum introduces thermal inertia.
Using the Bland-Altman approach, the mean difference between the two methods and the limits of agreement were determined (Figure 3). The bias of the BCT sensor was -0.029 °C, with 95% limits of agreement at −0.38 and +0.35 °C. Moreover, 100 % of the values lay within ±0.5 °C of the rectal temperature.

IV. **DISCUSSION – CONCLUSION**

Through this experiment, we have demonstrated that the BCT is a useful ambulatory device suitable for non-invasive monitoring. It can be used instead of rectal temperature measurement, used generally as a core body temperature reference, improving the comfort of the user and thus the acceptability of the measurement.
These encouraging results of this preliminary experiment on a limited number of subjects form the first stage towards the validation of this tool.

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