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Core and local skin temperature: 3–24 months old toddlers and comparison to adults

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ABSTRACT

The thermoregulatory responses, thermal sensation and comfort level of children are very different to those of the adult population, and should be considered in the modelling of thermal comfort and the use of climate control systems in children-shared spaces. In addition, thermoregulation is believed to be related with Sudden Infant Death Syndrome, a major cause of death in children aged below 1 year.

However experimental core and skin temperature data of the infant population is very limited, especially in toddlers. The present work investigates and reports the body core and local skin temperature characteristics of young children, as well as their dependency on gender, BMI, age, activity level and clothing. This study's novel features are:

i) clothed subjects were used and the gender representation was balanced;

ii) all subjects are children aged 3–24 months -not previously reported in the literature;

iii) it is comprehensive in terms of both infant subjects (N = 138) and total measurements (over 9000); and

iv) it compares the characteristic body and skin temperature in adult and infant population. We observed for instance that children's core temperature is higher than for adults, while their forehead and limbs' temperature increase with age. Also, core and skin temperature seem to become more dependent on BMI with age maturation.

1. Introduction

Thermoregulation is the ability of the body to maintain within a small range the internal temperature, predominantly aimed at maintaining constant brain temperature and only as a secondary response controlling the temperature of peripheral areas such as limbs. As the body temperature is very close to the limit of 42 °C the main concern is core overheating. The thermoregulatory system has been a focus of research interest for more than eighty years [1]. A number of predictive models of the human thermoregulatory response to environmental conditions [2–14] are being proposed as they increase in sophistication and level of complexity. In turn this increased complexity requires substantial expansion in the experimental database that is not currently available for infants.

Thermoregulation in infants is different [15–18], both during exposure to hot [15,17] and cold [17] environments; during rest [16,17] and exercise [17], evolving rapidly in the first few months after birth [19]. The evolution of the thermoregulatory system includes the emergence of circadian rhythmicity for core temperature [20], skin temperature and motor activity [21]. The difference in thermoregulation has been attributed to physical and physiological child-adult differences, i.e. morphological, locomotion-wise, cardiac output, sweating rates, etc. [17,18]. In terms of morphological differences, the higher surface area-to-mass ratio in children enhances the dry heat loss and heat absorption respectively and the smaller blood volume in infants may limit the potential for heat transfer during exposure to heat [17]. Infants also have lower tissue insulation and lower resting metabolic heat production per surface area [16]. The sweating mechanism is the main physiological difference affecting thermoregulation when exposed to heat [17], as the sweat response in infants is one third of that in adults despite them having a higher sweat gland density [16,22]. Also the onset of shivering occurs in children at a significant higher core temperature relative to the resting state [22]. These apparent thermoregulatory inferiorities that seemingly make children more vulnerable may

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List of abbreviations

BMI:	body mass index (subject's weight/height^2 in kg/m^2)
C:	covered by clothing (NC e not covered/exposed)
H_{room}:	average room relative humidity (%)
Status:	activity status of the infant {*awake*, *asleep*}
T_{room}:	temperature of the room during measurement sessions
Tc:	core body temperature
Ti:	temperature in the points of measurement {i = 1,2,…16,c}
i:	index for the different body locations as indicated in Table 2 or illustrated in Fig. 2. (i = c – indicates core body; i = 1 – forehead, i = 2 – back of the neck, etc)

only be relevant in extreme temperatures. However, there is a possibility that infants may exhibit alternative thermoregulatory responses at normal ambient conditions [18]. This statement is partially supported by Rowland's work [23] who found no difference in thermal balance, endurance performance or heat injury risk between children and adults undertaking exercise in the heat.

Body temperature and skin temperature distribution are reported in several studies on adults [3,24–29]. A relatively small number of studies investigated the differences and similarities between infants and adults [15,17,21,30–33] as discussed below but none addressed toddlers. Preterm newborn children of up to 13 days of age were observed to be already responsive to the operative temperatures within the incubators in the range of 28–32 °C, with skin temperatures dependent on the location [31,32]. The mean skin temperature significantly decreases when infants reach 3 months while their mean activity levels increase [21]. Three months-old infants sleep for longer when exposed to lower ambient temperatures [30]. Adaptation and local disparity continues while the children grow up, presenting higher mean and local skin temperatures (forehead, abdomen, instep) than adults both at thermoneutral conditions and heat exposure [15] as well as exercise activities [17]. Similarly skin temperature is lower than in adults when exposed to cold due to greater vasoconstriction [17]. However core temperature remains the same at thermoneutral environments [17] and while at rest [15], but it is significantly higher if exposed to heat [15]. The skin temperature in children is also different in terms of temperature distribution presenting lower variations across the body (x and y direction) [33].

Children have also been observed to differ in their thermal sensation, thermal comfort and temperature preference [22,34–37], being:

- more sensitive to cold and hot environmental temperatures than adults [34,37],
- more sensitive than adults to changes in their core temperature [22], and
- have a slower rate of heat acclimation [17].

Teli et al. [34] performed a large field study where school children aged 7–11 years assessed thermal sensation and preference within naturally ventilated classrooms. The authors found that the preferred room temperatures were about 2 °C lower than the value predicted by the adaptive comfort model used in the European Standard EN 15251, and even more significantly, they were 4 °C lower than the values predicted by the heat balance model that uses the PMV index. The latter (PMV) was also found unsuitable for the prediction of thermal sensation in children aged 9–11 years by Ter Mors et al. [36]. Another study by Teli et al. [35] showed that the thermal sensation was not dependent on the gender although male children usually preferred cooler environments than girl when subjected to high temperatures. The discrepancy between the experienced thermal sensation and comfort level of children in a given environment and the predictions obtained from adult-population models such as PMV clearly indicates the need to develop specific models for children to address their thermal requirements [35]. Alternatively children will continue to be subjected to classroom/kindergarten conditions that address teachers' preferences [38].

Furthermore thermoregulation is considered related with the sudden infant death syndrome (SIDS), which is the major cause of death in children up to 1 year of age, with SIDS accounting for more deaths than those from infections and allergies [16,37]. Skin temperature has been used in paediatric applications [39,40] as well as an indicator of thermal stress; however a good understanding of skin temperature distribution in healthy subjects is required in order to achieve reliable conclusions.

However the infant skin and core temperature studies to date [15,30–33] were conducted on small number of subjects [15], that were either newborns (up to 1 month of age) [31,32] or 2–14 years of age [33]. All of them were performed on naked children that is not representative to the every-day environment. Some data are historical and are no longer applicable as infants anthropometry has changed significantly in the last three decades [41]. Some utilised measuring techniques are questionable, some used thermistor probes attached to the skin with adhesive tape that might effectively increase the temperature in the area [30], while others used thermal cameras at a long distance [33] without reference temperature points for the correction of errors [42]. Furthermore current thermal comfort models do not apply to children [34,36]. There is also a strong current interest in implementing results from thermal sensation in climatic control using artificial intelligence [43], climatic control in shared spaces [44,45], influence of environment on sleep comfort [46] and thermal sensation in moderate activities [47]. In conclusion, the need for more research focused on children is recognized in the literature with suggestions of research on children thermal requirements in current and future climates [35]. The first necessary step is to investigate the differences in temperature distribution between children and adults in various regions, most sensitive index of temperature exposure, and sensitive impact of extreme temperatures [37].

The motivation for the current work was to improve the understanding of core body temperature and skin temperature distribution in young children aged 3–24 months. This is a particularly important group as they are not able to inform their carers of how they feel. The focus of the reported results is on clothed children at normal indoor climate conditions, i.e. mild room temperatures of 23.7 (SD 1.7) °C, no strong radiation temperature and 55.1 (SD = 6.8) % humidity.

The aims of this study were to:

i) obtain a map of the body temperature distribution based on a large number of samples among infants between 3 and 24 months of age,
ii) identify factors affecting the core temperature and local skin temperature distribution at selected locations based on the existing ISO standards 9886 [48], and
iii) compare the core temperature and local skin temperature of children with that of adults at similar environmental conditions.