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ORIGINAL ARTICLE

Evaluation of the thermal insulation of clothing of infants sleeping outdoors in Northern winter

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Abstract It is a common practice in Northern countries that children aged about 2 weeks to 2 years take their daytime sleep outdoors in prams in winter. The aim was to evaluate the thermal insulation of clothing of infants sleeping outdoors in winter. Clothing data of infants aged 3.5 months was collected, and sleep duration, skin and microclimate temperatures, humidity inside middle wear, air temperature and velocity of the outdoor environment were recorded during sleep taken outdoors ($n = 34$) and indoors ($n = 33$) in families' homes. The insulation of clothing ensembles was measured by using a baby-size thermal manikin, and the values were used for defining clothing insulation of the observed infants. Required clothing insulation for each condition was estimated according to ISO 11079. Clothing insulation did not correlate with ambient air temperature. The observed and required insulation of the study group was equal at about −5°C, but overdressing existed in warmer and deficiency in thermal insulation in colder temperatures (r_s 0.739, $p < 0.001$). However, even at −5°C a slow cooling (ca. 0.012°C/min) of mean skin temperature (T_{sk}) was observed. When the difference between observed and required insulation increased, the cooling rate of T_{sk} increased linearly (r_s 0.605, $p < 0.001$) and the infants slept for a shorter period (r_s 0.524, $p = 0.001$). The results of this study show the difficulty of adjusting systematically the optimal thermal insulation for outdoor sleeping infants during northern winter. Therefore, the necessity for guidelines is obvious. The study provides information for adequate cold protection of infants sleeping in cold conditions.

Keywords Clothing · Infant · Sleep · Microclimate temperature · Skin temperature · Cold climate

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Introduction

Considerable variation can be found in child care practices in different societies (Nelson et al. 2000). In Finland children take their daytime naps outdoors during winter from the age of about 2 weeks to 2 years (Tourula et al. 2008). The coldest outdoor air temperature in which parents let their child sleep in the daytime varies from −15°C to almost −30°C in some families (Tourula et al. 2008, 2010), but the best temperature was evaluated to be about −6°C (Tourula et al. 2008). Infants take longer naps outdoors than indoors, but faster cooling of skin temperature shortens the sleep duration (Tourula et al. 2010).

Infants are dressed in different ways in different societies, and these cultural factors affect the thermal environment of infants (Nelson et al. 2000; Watson et al. 1998). Infants in Japan and Korea have been described to sleep in bedding combinations of greater insulation than infants in New Zealand in comparable season indoors (Wilson and Chu 2005). Traditional outdoor infant care practices, for example swaddling and living in traditional tents called "Ger" in the Mongolian winter (Tsogt et al. 2006) as well as using the form of dressing called "manta pouch" in Peru (Tronick et al. 1994), have been described as protecting the infant from the cold. However, in our previous questionnaire study some parents in Finland estimated that their infants had cold extremities after sleeping outdoors in a pram (Tourula et al. 2008), and according to skin temperature measurements a decrease in ambient temperature increased the cooling rate of outdoor sleeping infants despite winter clothing (Tourula et al. 2010).

Tuohy and Tuohy (1990) suggested that parents may decide on the amount of indoor clothing of the infant based on outdoor temperature, and according to Bacon et al. (1991), based on their tradition and expectations rather than immediate conditions. McCullough et al. (2009) have developed a model for determining the insulation of cold weather clothing of children from the age of 4 years for the activity level of walking. Although thermal balance is greatly affected by clothing little is known about the usual amount of clothing worn (Bacon 1983; Nicoll 1986; Wailoo et al. 1989a) or what is required for the infant to keep in thermoneutral conditions during sleep (Wigfield et al. 1993), especially out of doors. The clothing insulation of infants sleeping outdoors for a few hours under the severe cold environments of northern latitudes becomes of great significance.

The aim of this study is to evaluate the thermal insulation of the clothing of infants sleeping outdoors in Northern Finland in winter purposing to provide new scientific information for guidelines. We compare the microclimate temperatures between outdoor and indoor sleeping infants, define outdoor clothing insulation and compare it to required clothing insulation (IREQ) and examine how the deficit of insulation affects the cooling rate of mean skin temperature (T_{sk}) and sleep duration.

Methods

Measurement protocol

Selection criteria included healthy outdoor-sleeping infants aged about 3 months. The infants were recruited through public health nurses in the child health clinics and using parents' social network and snowball sampling. Thirty-four infants (17 girls, 17 boys) participated in the measurements, 33 during both outdoor and indoor daytime sleep and one during outdoor sleep only. Approval from the Ethical Committee of the Northern Ostrobothnia Hospital District and written informed consent from the parent of each infant was obtained for the study.

The skin and microclimate temperatures were recorded between January and March 2007 and between December 2007 and March 2008 in the natural settings of the families' homes in rural areas and towns in Northern Finland. Parents decided the limits of outdoor temperatures and weather conditions in which they let their child sleep outside as well as infant's clothing and wrapping used during outdoor ($n = 34$) and indoor ($n = 33$) daytime sleep. Duration of the infant's sleep and specific data on clothing were collected. Sweatiness was estimated immediately after sleep by palpating the infants. Skin temperature (7 sites) measurements were described in our previous article (Tourula et al. 2010).

Microclimate temperatures of the infants' clothing were recorded at the same time as skin temperatures (Tourula et al. 2010) with probes (NTC DC95, type 22520HM, DIGI-KEY, Thief River Falls, MN, USA) located during outdoor sleeping inside the middle layer (T_1), inside the infant's snowsuit (T_2), inside the sleeping bag (T_3), and 50 cm from the pram (T_a), and indoors: inside the middle layer if used (T_4), inside the covering (T_5), and 50 cm from the cot (T_a). All clothing probes were placed on the left side on the infant's chest. The probes were connected to a datalogger (SmartReader 8, ACR Systems Inc., Vancouver, Canada), which recorded temperatures at one-minute intervals. Air velocity was measured 100 cm from the pram by using an anemometer (Testo 491; Testoterm GmbH & Co., Lenzkirch, Germany). Humidity was recorded every 5 min with a miniature temperature and humidity recorder (OM-CP-MicroRHTemp, OMEGA, USA) placed on the infant's underclothing, on the infant's abdomen during the sleep indoors ($n = 24$) and outdoors ($n = 25$).

The 8-segmented baby thermal manikin (Kyoto Electronics manufacturing Co., Ltd) was used for the calculation of clothing ensembles' insulation. The manikin represented an about 4-month-old infant with a body surface area of 0.311 m^2, a weight of 5.7 kg, and height of 60 cm. The manikin was laid on three mattresses (Table 1, No 1–5) or on one mattress of the pram (Table 1, No 6–9) in supine position, which was how most infants slept while napping outdoors. Each segment of the manikin was separately heated to 33.0°C. After reaching steady state, the computer system was set to make recordings every minute over ten-minute periods. The experiments were performed in a thermal chamber with air temperature (T_a) set at −10°C and relative humidity at 50% for clothing ensembles No 3–9 and at +22°C for clothing ensembles No 1–2 (Table 1).

Table 1 Thermal insulation of clothing ensembles in units of clo and $m^2 °C W^{-1}$ according to baby thermal manikin measurements

Ensemble no.	Clothing ensembles	I_t (parallel)	I_{cle}
1	Bodysuit, disposable nappy, footed leggings, mattresses	1.19/0.18	0.53/0.08
2	Bodysuit, disposable nappy, footed leggings, blanket and duvet cover, mattresses	1.95/0.30	1.30/0.20
3	Bodysuit, disposable nappy, footed leggings, mittens, woolen socks, woolen cardigan and pants, balaclava hat, mattresses	2.11/0.33	1.45/0.22
4	Bodysuit, disposable nappy, footed leggings, mittens, woolen socks, woolen cardigan and pants, balaclava hat, insulated booties, woolen hat, snowsuit, mattresses	4.07/0.63	3.41/0.53
5	Bodysuit, disposable nappy, footed leggings, mittens, woolen socks, woolen cardigan and pants, balaclava hat, insulated booties, woolen hat, snowsuit, sleeping bag, mattresses	4.82/0.75	4.16/0.64
6	Bodysuit, disposable nappy, footed leggings, mittens, woolen socks, woolen cardigan and pants, balaclava hat, insulated booties, woolen hat, snowsuit, sleeping bag, pram	6.26/0.97	5.60/0.87
7	Bodysuit, disposable nappy, footed leggings, mittens, socks, balaclava hat, woolen hat, snowsuit, sleeping bag, pram	5.67/0.88	5.01/0.78
8	Bodysuit, disposable nappy, footed leggings, mittens, socks, woolen socks, woolen mittens, playsuit (shirt and pants), woolen cardigan and pants, overall with wadding, balaclava hat, insulated booties, insulated mittens, insulated hat, snowsuit, Eisbärchen sleeping bag, sheepskin, pram	8.07/1.25	7.41/1.15
9	Bodysuit, disposable nappy, footed leggings, playsuit, mittens, socks, overall with wadding, balaclava hat, insulated mittens, insulated booties, insulated hat, snowsuit, sleeping bag, pram	6.06/0.94	5.40/0.84

The clothing insulation measurements with the manikin consisted of nine ensembles (Table 1). Ensemble No 2 represented a clothing ensemble worn indoors, No 7 the least and No 8 the most clothes that an infant wore outdoors in winter. No. 9 consisted of clothes from the Maternity package version 2008 distributed to expecting mothers in Finland by the Social Insurance Institution of Finland. The use of clothes in the maternity package is common: in 2008, 42,400 packages were distributed in Finland (Kela 2009).

Data analysis

The total thermal insulation (It, thermal insulation from the body surface to the environment including all clothing, enclosed air layers and boundary air layer) of clothing ensembles was calculated using the equation of parallel method (temperature gradient divided by surface area averaged heat loss), because the manikin surface temperatures remained uniform (ISO 15831, 2004; ISO 9920, 2007).

Effective clothing insulation (I_{cle}) is the additional insulation provided by clothes compared to the nude manikin. The clo unit (1 clo = 0.155 $m^2 °C/W$) expresses the thermal insulation of the clothing ensemble (ISO 9920, 2007).

Clothes were washed twice before measurements. Three measurements were made for each clothing ensemble to ensure reliability. Insulation values of the clothing ensembles given in this study are the arithmetic mean of single test results. The coefficient of variation of clothing ensemble's insulation (I_t) was less than 7%.

The thermal insulation of the selected clothing ensembles (Table 1) was assessed by thermal manikin measurements, based on which the thermal insulation of different clothing items was calculated. For the estimation of the thermal insulation of clothing ensembles worn by infants during outdoor sleep, the nearest matching ensemble from the manikin measurements was selected. If the observed clothing ensemble was different from that measured using the manikin, the ensemble insulation was corrected by adding or reducing the insulation of different items (ISO 9920, 2007).

The required clothing insulation ($IREQ_{neutral}$) values were calculated by using the mathematical model (ISO 11079, 2007) for analyzing whether or not the observed clothing ensembles worn by outdoor sleeping infants provided insulation that was sufficient to maintain thermal neutrality. IREQ (I_{cl}) of every outdoor sleeping infant was defined individually by using values of mean outdoor air temperature and air velocity measured during each sleeping situation. The metabolic rate of sleeping infants in thermoneutral conditions was estimated to be 50 W/m^2. It is the average from earlier studies: 28–55 W/m^2 (Arkell et al. 2007), mean (SD) 45(10) W/m^2 (Hull et al. 1996a, b) and 53–60 W/m^2 (Rising et al. 2003). The difference between observed clothing insulation in use and IREQ [observed clothing insulation (clo) − required clothing insulation (clo)] was calculated. In addition to the individual IREQ value, also general IREQ was calculated by using air velocity of 0.4 m/s, which was the mean value during the outdoor sleeping situations ($n = 34$), and relative humidity of 85%, which was the mean value in northern Finland from November to March (FMI 2009).

For statistical analysis, SPSS version 16.0 for Windows (SPSS Inc., Chicago, IL, USA) was used. Paired-samples t test was used to compare mean temperatures at the point of 60 min (T_{1-3}) outdoors with mean temperatures at the point of 30 min (T_5) indoors ($n = 33$). Infants slept for a shorter time indoors than outdoors (Tourula et al. 2010), which is why the most stabile moment was at different times. Paired-samples *t* test was used when observed (clothing in use) and predicted (IREQ) insulations of clothing ensembles were compared. Correlations were calculated by using the Spearman correlation coefficient. Linear regression was used for predicting relationships between cooling rate of T_{sk} and the difference between observed and required insulations as well as between outdoor air temperature and the difference between observed and required insulation. Mean difference between central (chest) and peripheral (dorsal foot) skin temperature in the course of time was used for assessing the effect of exposure time.

Results

Thermal insulation measured with the manikin

The total thermal insulation (I_t) of the outdoor used clothing ensembles no. 6–9 with the pram ranged from 5.67 to 8.07 clo (Table 1). The insulation of the clothed manikin (no.5, Table 1) increased by 1.44 clo/0.22 m^{2}°CW^{-1} when the manikin was laid in the pram. Underwear accounted for 10%, middle layer for 16%, outerwear for 35%, covers for 13% and pram for 26% of the insulation.

Environments and microclimate temperatures of sleeping infants

Infants' mean (SD) age was 14.3 (3) weeks, weight 6,215 (1,001) g and height 60.9 (3.9) cm. The mean (SD) age of mothers was 31 (5) years; 14 of them had one child, while the others had 2–9 children.

The outdoor sleeping infants were exposed to many kinds of environments in the winter: they slept in prams from sunshine to heavy snowfall and mean ambient air temperatures ranging from −25.9 to 2.2°C [mean (SD) of −5.9 (5.9)°C]. Mean air velocity was 0.4 m/s. Air velocity ranged instantly from 0 to 9 m/s during the measurements and the mean velocity from 0 to 2.23 m/s. Infants slept in prams on the balcony, veranda or in the garden, and some mothers went for a walk with their sleeping infants. When staying indoors, infants slept in cots or prams, the mean (SD) room temperature (T_a) being 22.1 (1.5)°C.

The cold ambient air temperature came in close contact with the sleeping infants. When the infants had slept for 60 min outdoors the mean temperature inside the middle layer (T_1) was 1.6°C (95% CI: 0.4–2.9°C, $p = 0.014$) warmer than indoors inside the blankets (T_5) when the infants had slept for 30 min, whereas the mean temperature inside the snowsuit (T_2) was 3.5°C (95% CI: 5.6–1.5°C, $p = 0.002$) colder and mean temperature inside the sleeping bag (T_3) 18.2°C (95% CI: 20.3–16.2, $p < 0.001$) colder outdoors than indoors inside the blankets (T_5).

Cold ambient air temperature cooled down (r_s 0.442, $p = 0.011$) the temperature inside the middle layer (T_1), which led to a decrease (r_s 0.533, $p = 0.002$) in mean skin temperature (T_{sk}). The mean difference between central (chest) and peripheral (dorsal foot) skin temperature exceeded the start difference (2°C) when infants ($n = 10$) had slept for more than 200 min.

Clothing insulation and comparison with IREQ

Clothes and beddings did not vary much indoors. Infants were usually clad in a bodysuit, disposable nappy, footed leggings (sometimes tights, or leggings with socks or a romper suit) and covers (blanket and duvet cover or sleeping bag). The underwear worn with the outdoor clothing ensembles was congruent with that of the indoor clothing ensemble. The middle layer had greater variability in amount and quality, consisting of a balaclava hat, socks (usually woolen, handmade), mittens (cotton or woolen), shirt and pants/overall (cotton, fleece or woolen). Outer garments consisted of a hat (cotton, woolen or insulated), snowsuit with hood and insulated mittens and booties. Sleeping bags were commonly used, usually those included in the maternity package (62%) and in some case thicker sleeping bags. Five infants slept on a sheepskin. Different kinds of pram models were used, and in nearly all cases (82%) the hood of the pram was covered with gauze, net or cloth.

The observed mean (SD) clothing insulation (I_{cle}) of outdoor sleeping infants ($n = 34$) was estimated to be 5.54 (0.52) clo, ranging from 4.35 to 6.47 clo. Calculated individual IREQ-values did not differ significantly from observed clothing insulations ($p = 0.263$), although no correlation between IREQ and observed clothing insulation was not found, either (r_s 0.076, $p = 0.670$).

Observed clothing insulation did not correlate with T_a (Fig. 1). The deficit of clothing insulation increased when T_a decreased below −5°C, and overdressing existed when T_a was higher than −5°C (Fig. 2). The cooling rate of T_{sk} increased linearly outdoors (r_s 0.605, $p < 0.001$) (Fig. 3), and the infants slept for a shorter time outdoors (r_s 0.524, $p = 0.001$) when the difference between observed and required clothing insulation increased.

According to IREQ calculations (ISO 11079, 2007), thermal insulation (I_{cle}) of the minimum amount of winter clothes (5.01 clo/0.78 m^{2}°CW^{-1}) is required during infants' sleep in ambient temperature of about −1°C and maximum amount of clothes (7.41 clo/1.15 m^{2}°CW^{-1}) in ambient temperature of about −17°C. The clothing ensemble

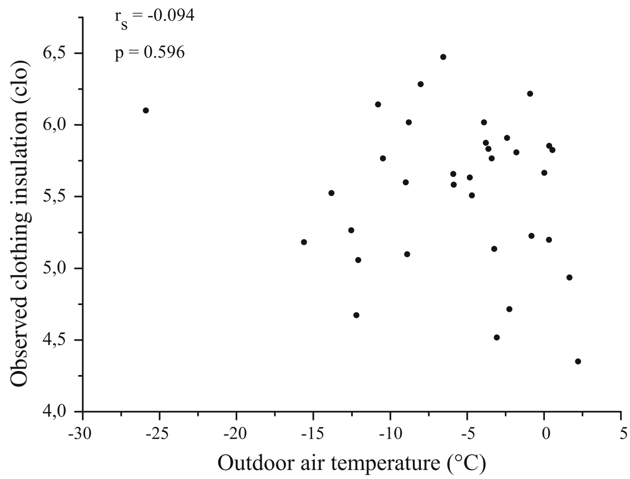

Fig. 1 Observed clothing insulation (clo) at different outdoor air temperatures (°C)

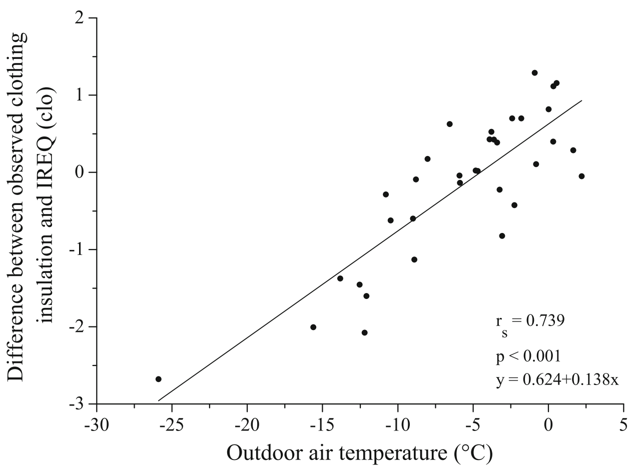

Fig. 2 The difference between observed and required (IREQ) thermal insulation of clothing (clo) at different outdoor air temperatures (°C)

consisting of the clothes from the Finnish Maternity package plus pram (Table 1, No 9) had an insulation value of 5.40 clo/0.84 $m^2{}^\circ CW^{-1}$, meaning that it provides insulation for a sleeping child in ambient temperature of about −5°C.

Humidity between clothing layers

Thirty-two percent of infants sleeping outdoors were estimated to be warm or sweaty, compared to none after indoor sleeping. Mean humidity (RH%) between clothing layers ranged during outdoor sleeping from 22.6 to 64.5% with a mean (SD) of 35.3 (9.7)%, and during indoor sleeping from 21.0 to 62.9% with a mean (SD) of 32.6 (10.1)%. Humidity was on average 40% at the beginning of outdoor sleeping. Individual variations were found in the humidity trends outdoors; in general there was a decreasing trend, but in some cases ($n = 4$) humidity increased. There was a clear association with maximum T_{sk} and humidity (r_s 0.747, $p = <0.001$)

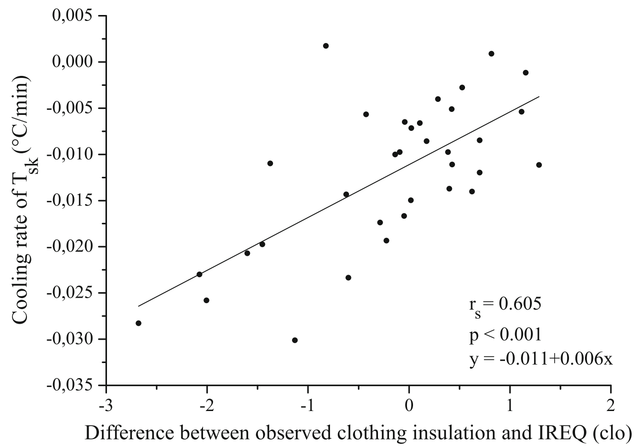

Fig. 3 The correlation between the cooling rate of T_{sk} (°C/min) and the difference between observed and required (IREQ) thermal insulation of clothing (clo). Positive clo-value shows overdressing and negative deficit of insulation

during outdoor sleeping, but this was not noticed indoors (r_s 0.107, $p = 0.619$). Humidity was >30 RH% when mean T_{sk} was >32.5°C during outdoor sleeping. At different skin sites, the biggest correlation was seen between mean temperature of cheek and humidity (r_s 0.587, $p = 0.002$). Humidity correlated significantly with the temperature of middle layer (r_s 0.471, $p = 0.023$), but not with clothing insulations (r_s 0.088, $p = 0.677$) or outdoor temperature (r_s 0.102, $p = 0.627$).

Discussion

Our results show that the selection of thermal insulation of clothing was not always sufficiently based on outdoor air temperature, which is in line with the findings of Bacon et al. (1991). The commonly used clothing ensemble from the Finnish maternity package and pram gives appropriate insulation at −5°C; probably due to this it seems that observed and required thermal insulation of clothing was equal at around −5°C. Accordingly, also in our questionnaire study (Tourula et al. 2008) parents estimated the best temperature for letting the child sleep outdoors to be about −6°C. It shows that parents have the ability to make observations about their child's wellbeing.

Even when the difference between observed and required thermal insulation was ≥0 clo, a slow cooling of T_{sk} was observed. It may be caused by diurnal variation, a sleep-induced decrease in body temperature or return to normal temperature after initial overheating due to dressing procedures indoors (Tourula et al. 2010). A circadian rhythm of rectal temperature exists from the age of 2–4 months (Lodemore et al. 1992). However, skin temperatures seem to reflect microclimate (Tourula et al. 2010) rather than diurnal variation (Wailoo et al. 1989b). Infants were dressed in layered winter clothes and put in prams indoors before going outdoors, causing heat accumulation and higher skin temperature at sleep onset when compared to indoor sleeping (Tourula et al. 2010).

Comparison of observed and required clothing insulation showed that increase of deficiency in thermal insulation was associated with faster cooling rate of T_{sk}. Infants responded to cooling by shortening the duration of sleep (Tourula et al. 2010), which is in line with the study of Eiser et al. (1985), in which the mothers interviewed reported that the infants became irritable when too cold. Although most infants seem to react to cold exposure and increased cooling rate by waking up (Tourula et al. 2010), central-peripheral temperature difference increased above 2°C in infants who had a slow cooling rate as well as more than 200 min of sleep. Central-peripheral temperature difference has been suggested to be a better indicator of the thermal state of the infant than a single skin temperature alone, and a difference of more than 2°C may have an effect on heart rate and blood pressure of very low birth weight infants. (Lyon et al. 1997).

The sleeping child should be observed frequently, which many parents do (Tourula et al. 2008) when the baby is sleeping outdoors. The child should also be taken indoors at the latest when he or she has slept outdoors for 200 min, especially if it is colder than −5°C. The duration of outdoor sleeping ranged from 83 to 300 min (Tourula et al. 2010). When the insulation of clothing ensembles in use is less than the required insulation, the body cannot maintain thermal balance during a long nap outdoors, which is why sleeping time has to be limited to prevent progressive cooling (ISO 11079, 2007). In practice, the cooling-induced awakening of infants may interrupt the cold exposure. Special attention should be paid to children with neurological disorders with cold extremities (Svedberg et al. 2005) and Raynaud's phenomenon (Nigrovic et al. 2003) because of their increased risk of frostbite. Moreover, facial cooling alone with inhalation of warm air can increase bronchoconstriction in children with mild asthma (Zeitoun et al. 2004).

In our study some infants were also too heavily clothed, which was seen as higher level of T_{sk} and relative humidity inside the middle layer. This is in line with the findings of Grover et al. (1994), where bundling a healthy infant in a temperate environment was shown to cause an increase in skin temperature. In the present study, cheek temperature had a significant positive correlation with microclimate humidity measured on the chest, which suggests that the head plays an important role in heat loss. This is in line with previous studies showing that in dressed infants most of the heat loss occurs via the head (Elabbassi et al. 2002; Stothers 1981), especially the face (Nelson et al. 1989). Elabbassi et al. (2002) have cautioned against overheating of the brain by reducing heat loss from the head of heavily dressed newborns, while Mitchell et al. (2008) support the recommendation of avoiding head covering as part of SIDS (sudden infant death syndrome) prevention strategies. Therefore, to avoid overheating or cooling, cold protection of the head of outdoor sleeping infants should be given special attention.

Overheating of infants due to excessive bedding and clothing and its relevance to SIDS has been widely studied (Baddock et al. 2004; Fleming et al. 1990; Nelson et al. 1989; Ponsonby et al. 1992; Watson et al. 1998; Wigfield et al. 1993; Wilson and Chu 2005; Wilson et al. 1994), but hardly any studies mention the association between SIDS and too little thermal insulation (Williams et al. 1996). Little is known about the associations between climatic factors and child health (review of Bunyavanich et al. 2003). The physical environment encompasses many factors such as air pollution, lead, chemicals and noise, which all have effects on children's health (Pond et al. 2007), but discussion about cold exposure connected with this wider topic of children's environmental health is lacking.

The results of this study show that traditional infant care practice was not always precise enough for maintaining infants' thermal comfort in a cold outdoor environment. This was not found to exist among traditional care in Mongolia (Tsogt et al. 2006) or in Peru (Tronick et al. 1994). However, children sleep longer (Tourula et al. 2010) and parents have mainly positive experiences of children sleeping outdoors in Finland (Tourula et al. 2008). Scientifically based guidelines of children's cold protection and sleeping in different kinds of weather conditions should still be considered. Hull et al. (1996a, b) support giving general advice and reinforcing parents' awareness of infants' sweatiness and coldness and adjusting the amount of clothing insulation in accordance with ambient air temperature, rather than giving more specific advice, due to wide variation in infants' sleeping metabolic rates. The relative risks and benefits should be considered, providing evidence-based information to fit the individual needs and the cultural context of the family (Morgan et al. 2006).

Limitations

In this study, the thermal insulation of the outdoor sleeping infants included both clothes and prams. The reduction of air insulation when there is a large outer surface area due to a pram has been included in our calculations. Previous studies (Ponsonby et al. 1992; Watson et al. 1998; Wigfield et al. 1993) have used the thermal balance model based on the formula of Burton and Edholm (1969) instead of our methods (ISO 11079, 2007), making it difficult to compare the results (Wilson et al. 2004).

We used both a thermal manikin to define clothing insulation values of each outdoor sleeping infants and human subjects. The size of the manikin was identical with the study infants and the clothes were well-fitted, strengthening the reliability of the study (Kuklane et al. 2004). However, there are number of factors, that could not be taken into consideration in the evaluation of clothing insulation, such as variation in how well the clothes fit different infants, different kinds of prams or whether the covers were tightly or loosely placed over the infant, the reduction in insulation of clothes that have been washed or wetted a lot as well as body movements (ISO 9920, 2007) and sleep posture (Wilson and Chu 2005).

According to Hull et al. (1996a, b), in their first year of life infants have wide individual variation in metabolic rates, and it should be noted that calculation of IREQ has been applied to the average person, which is why the interpretations may only serve as a guideline for the individual (ISO 11079, 2007).

In conclusion, the results of this study show the difficulty of adjusting systematically the optimal thermal insulation for outdoor sleeping infants during northern winter. Therefore, the necessity for guidelines is obvious. The study provides information for adequate cold protection of infants sleeping in cold conditions.

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Conflict of interest The study sponsors had no role in the study design, in the calculation, analysis, or interpretation of data, in the writing of the report, or in the decision to submit the article for publication. The authors have no competing financial interests.

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