

# Heated Cot Use during the First Postnatal Days in Term Neonates: A Multicentre Retrospective Observational Study

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## Keywords

Thermoregulation; Term Neonates;  
Heated Cot; Warmth Mattress; Neonatal Care

## Abstract

### Purpose

Maintaining normothermia is a key component of optimal neonatal care, as both hypothermia and hyperthermia are associated with increased morbidity and mortality across gestational ages. This study evaluated the relationship between the use of heated cot and thermal outcome during the first postnatal days.

### Methods

This multicentre retrospective comparative study included healthy neonates (N= 1371) born at ≥36 weeks gestation and weighing >2.2 kg in two maternity units using different thermoregulatory protocols: heated cot care versus standard cot care. The primary outcome was normothermia; secondary outcomes included hypothermia and hyperthermia.

## Results

Heated cot use was associated with significantly more normothermia (OR 1.48, 95% CI 1.28–1.72) and less hypothermia (OR 0.51, 95% CI 0.42–0.63), but significantly more hyperthermia (OR 1.72, 95% CI 1.28–2.31). These associations were time-dependent, as demonstrated by a significant interaction between heated cot use and postnatal age for normothermia and hypothermia. In neonates small for gestational age, heated cot use was associated with both higher odds of normothermia (OR 2.0, 95% CI 1.35–2.95) and lower odds of hypothermia (OR 0.42, 95% CI 0.26–0.67). Similar non-significant trends were observed with lower birthweight and gestational age.

## Conclusions

Heated cot use was associated with more normothermia and less hypothermia, but also more hyperthermia. Routine use in all healthy neonates may not be warranted, although selected high-risk neonates may benefit.

## Introduction

Maintaining normothermia is essential for optimal neonatal care, as both hypo- and hyperthermia are linked to increased morbidity and mortality across all gestational ages (1–4). All newborns are at risk of thermoregulatory instability due to a high surface-to-weight ratio, high metabolic rate, limited glycogen stores, and immature thermoregulation (2–6), with preterm infants being at highest risk due to additional anatomical and physiological immaturity. Risk of thermoregulatory instability is further increased by low birth weight, asphyxia, congenital anomalies, low environmental temperature, and socio-economic and knowledge-related factors (3,5,7). Hypothermia in newborns leads to increased metabolism to normalize temperature. Consequently, this increases oxygen and glucose consumption, putting the newborn at risk for respiratory and metabolic problems,

such as acidosis and hypoglycaemia (6). Either hypoglycaemia leads to hypothermia due to limited glycogen storage, or hypothermia leads to hypoglycaemia due to energy consumption to maintain body temperature (8). Prolonged cold stress may result in delayed transition from foetal to neonatal circulation and is associated with poor weight gain, neurological complications, coagulation defects, impaired cardiac function, jaundice, haemorrhage and even death (3,6,9). Notably, hyperthermia has also been associated with morbidity, including irritability, apnoea, poor feeding, dehydration, and tachycardia (4).

Heat loss occurs through evaporation of fluid from the skin immediately after birth, radiation to the cooler environment, conduction when the infant is placed on cold surfaces, and convection caused by air movement (9). Based on these principles, recommendations include providing a warm delivery room at

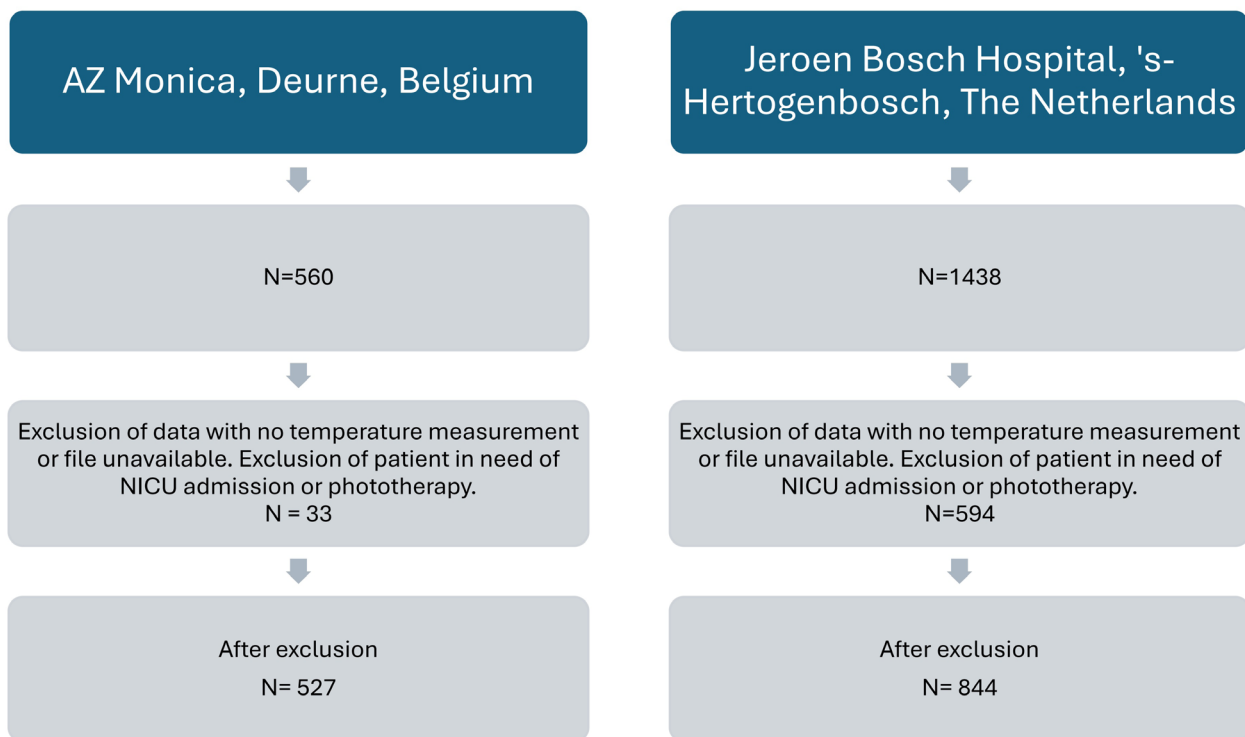


FIGURE 1: Patient screening and inclusion within the prespecified study window at Jeroen Bosch Ziekenhuis ('s-Hertogenbosch) and AZ Monica (Deurne). Exclusion criteria and numbers are shown per centre.

25°C, immediately drying the infant and removing wet blankets, covering the neonate with a clean blanket, and keeping the baby skin to skin to the mother, since kangaroo mother care improves thermoregulation. The use of preheated blankets and surfaces and radiant warmers is an additional support of thermoregulation (2–4,6,9–14). External heat is of importance, especially in lower environmental temperatures such as the operating theatre for term and preterm infants (15).

For vulnerable populations, such as premature infants, heat loss preventing strategies such as incubator care, radiant warmers, heated cots, and continuous temperature monitoring have been extensively studied and are widely implemented in neonatal care units (4,16). Although the importance of thermoregulation in the immediate postnatal period is well established and reflected in the WHO guidelines, guidance on thermoregulation for term and late preterm infants admitted to maternity wards during the first days of life is considerably less well defined (9). As a result, approaches to maintain normothermia in this population vary substantially between institutions and countries. For instance, in several Dutch hospitals, use of heated cots is standard of care to manage thermoregulation in newborns during the first days of life. In contrast, in most Belgian hospitals, normothermia is managed in a cot with blankets, without external heat sources. Proposed advantages of heated cots include the ability to easily adjust temperature following the individual need of each newborn and the awareness for adequate thermoregulation. However, these devices are

more expensive, their sustainability is questionable, and it requires extra maintenance compared to care in a standard cot.

Consequently, there is a lack of evidence regarding the benefit of heated cots for maintaining normothermia and preventing hypothermia and hyperthermia in late preterm and term newborns cared for in maternity units. The aim of this study was to compare two thermoregulatory strategies and to evaluate whether heated cot use was more effective than standard care in maintaining normothermia during the first days of life.

## Methods

### Population

#### *Inclusion criteria*

This multicentre retrospective comparative study included healthy neonates ( $\geq 36$  weeks;  $>2.2$  kg) admitted to the maternity units of two non-university hospitals with different temperature regulation protocols. The Belgian centre constituted the control group, while the Dutch centre implemented a heated cot protocol. All infants born between December 2023 and February 2024 (defined as winter) and between June and August 2024 (defined as summer) were included in the analysis (Figure 1).

TABLE 1: Overview of patient characteristics.

| Variables                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Non-heated cot       | Heated cot           | p-value    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----------------------|------------|
| <b>N = 1371</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | N = 527              | N = 844              |            |
| <b>Born in summer, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 285 (54%)            | 437 (52%)            | 0.438 (1)  |
| <b>Born in winter, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 242 (46%)            | 407 (48%)            | 0.438 (1)  |
| <b>Sex, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                      |                      | 0.076 (1)  |
| female                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 271 (52%)            | 392 (46%)            |            |
| male                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 255 (48%)            | 452 (54%)            |            |
| <b>GA, weeks</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                      |                      | 0.587 (2)  |
| mean $\pm$ SD                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 39.59 $\pm$ 1.11     | 39.63 $\pm$ 1.28     |            |
| median (Q1, Q3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 39.71 (38.86, 40.43) | 39.57 (38.79, 40.71) |            |
| <b>Delivery method, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | *                    |                      | 0.001 (1)  |
| assisted                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 45 (8.5%)            | 90 (11%)             |            |
| Caesarean                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 106 (20%)            | 234 (28%)            |            |
| vaginal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 376 (71%)            | 520 (62%)            |            |
| <b>Birthweight, kg</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                      |                      | 0.004 (2)  |
| median (Q1, Q3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 3,426 (3,100, 3,692) | 3,490 (3,135, 3,880) |            |
| <b>Birthweight category, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | **                   |                      | <0.001 (1) |
| LGA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 43 (8.2%)            | 141 (17%)            |            |
| AGA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 423 (80%)            | 590 (70%)            |            |
| SGA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 61 (12%)             | 113 (13%)            |            |
| <b>Feeding, (n = 1317) (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                      |                      | <0.001 (3) |
| breastfeeding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 406 (77%)            | 557 (70.5%)          |            |
| formula feeding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 61 (11.6%)           | 233 (29.5%)          |            |
| combination                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 60 (11.4%)           | -                    |            |
| <b>Maternal diabetes, n (%)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                      |                      | 0.3 (3)    |
| no                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 492 (93%)            | 796 (94%)            |            |
| yes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 35 (6.6%)            | 48 (5.7%)            |            |
| <b>APGAR</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                      |                      |            |
| APGAR 1min (n = 1350)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 8.73 $\pm$ 0.98      | 8.52 $\pm$ 1.50      | 0.090 (2)  |
| APGAR 5min (n = 1350)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 9,539 $\pm$ 0,651    | 9,623 $\pm$ 0,848    | <0.001 (2) |
| APGAR 10min (n = 1062)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 9,867 $\pm$ 0,367    | 9,821 $\pm$ 0,542    | 0.773 (2)  |
| <b>Temperature measurements during hospital stay</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                      |                      | <0.001 (2) |
| mean $\pm$ SD                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 7,54 $\pm$ 2,87      | 7,47 $\pm$ 4,72      |            |
| median (Q1, Q3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 7 (6, 9)             | 6 (4, 10)            |            |
| <b>Hospital hours (h)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                      |                      | <0.001     |
| mean $\pm$ SD median                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 64,9 $\pm$ 20,6      | 25,7 $\pm$ 15,7      |            |
| Median (Q1, Q3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 67 (55, 79)          | 15.2 (5.9, 24.4)     |            |
| GA: gestational age, LGA: large for gestational age, SGA: small for gestational age; AGA: appropriate for gestational age. Statistical analysis (1) chi square test (2) Mann Withney U test (3) Fisher test. * Post hoc pairwise comparisons: difference in vaginal deliveries and Caesarean sections (p_adj=0.002). **Post hoc pairwise comparisons: difference in AGA and LGA (both p_adj<0.001), no difference for SGA (p_adj=0.98). p_adj values were adjusted for multiple post hoc comparisons using the Bonferroni method |                      |                      |            |

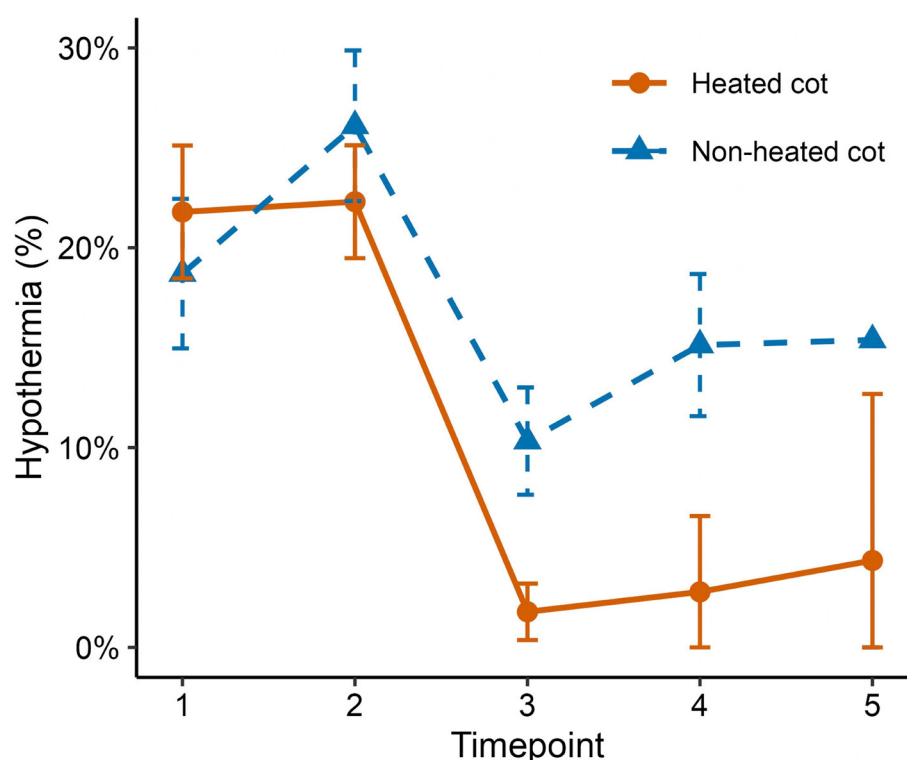


FIGURE 2: Percentages of hypothermia by timepoints with 95% confidence intervals. Solid red line = heated cot group. Dashed blue line = non-heated cot group. t1 (0–2 hours), t2 (2–24 hours), t3 (24–48 hours), t4 (48–96 hours), and t5 (>96 hours after birth).

### Exclusion criteria

Neonates requiring neonatal intensive care (e.g., for prematurity, low birth weight, or suspected infection requiring antibiotics) or phototherapy were excluded.

### Outcomes and definition

The primary research question was whether heated cot use was associated with a higher proportion of normothermic neonates during the first days of life compared with standard cot care. Secondary research questions examined the association of heated cot use with hypothermia, hyperthermia, hypoglycaemia, and postnatal weight loss. Study outcomes were defined a priori. Normothermia was defined, according to the World Health Organization, as all recorded temperatures remaining within 36.5–37.5 °C throughout the observation period (9). Temperature measurements were categorized across five postnatal time intervals: t1 (0–2 h), t2 (2–24 h), t3 (24–48 h), t4 (48–96 h), and t5 (>96 h). Hyperthermia was defined as any recorded temperature >37.5 °C (mild, 37.5–38.0°C; moderate, >38.0 °C or ≥2 temperatures >37.5 °C) and hypothermia any temperature <36.5 °C (mild, 36.0–36.5 °C; moderate, <36.0 °C or ≥2 temperatures <36.5 °C). Hypoglycaemia was defined as blood glucose <50 mg/dL before 48 h or <60 mg/dL after 48 h (17).

The exposure of interest was heated cot use (heated cot versus standard cot care). The following variables were collected a priori as potential confounders:

Apgar score at 1, 5 and 10 minutes; mode of delivery (caesarean section versus vaginal); feeding type; postmenstrual age; birth weight; birth weight category; percentage of postnatal weight loss; length of hospital stay (hours); maternal diabetes; and neonatal blood glucose measurements. Birth weight category was defined as small for gestational age (SGA; birth weight <p10), appropriate for gestational age (AGA; birth weight p10–p90), or large for gestational age (LGA; birth weight >p90). The percentage of postnatal weight loss was calculated as the lowest weight recorded during admission relative to birth weight. Effect modifiers are described separately in the statistical analysis section.

### Study interventions

In the control group (AZ Monica, Deurne, Belgium), infants were nursed in standard cots with skin-to-skin care and additional clothing. Temperature was checked after birth and monitored at least twice daily, or more frequently if an abnormal value was found (below 36.5 °C or above 37.5 °C). When hypothermia was observed, skin-to-skin care was encouraged; when this was not possible, the infant was covered with extra clothing and sheets. In the heated cot group (Jeroen Bosch Hospital, 's-Hertogenbosch, The Netherlands), all infants were nursed on heated cots (Vab CosyTherm2) in addition to skin-to-skin care and routine temperature monitoring. The heat mattress is set at 37.5°C by default. If the temperature of the neonate is below 36.5°C, in the impossibility

TABLE 2: Overview of Temperature Outcomes.

| 2a. Overview of Normothermia, Hypothermia and Hyperthermia |                |             |            |
|------------------------------------------------------------|----------------|-------------|------------|
| Variables                                                  | Non-heated cot | Heated cot  | p-value    |
| N = 1371                                                   | N = 527        | N = 844     |            |
| Normothermia, n (%)                                        | 221 (41.9%)    | 414 (49.1%) | <0.001 (1) |
| Hypothermia, n (%)                                         | 240 (45.5%)    | 268 (31.8%) | <0.001 (1) |
| Mild hypothermia, n (%)                                    | 136 (25.8%)    | 139 (16.5%) | <0.001 (1) |
| Moderate hypothermia, n (%)                                | 104 (19.7%)    | 129 (15.3%) | 0.032 (1)  |
| Hyperthermia, n (%)                                        | 110 (20.9%)    | 226 (26.8%) | <0.001 (1) |
| Mild hyperthermia, n (%)                                   | 127 (24.1%)    | 337 (39.9%) | <0.001 (1) |
| Moderate hyperthermia, n (%)                               | 48 (9.1%)      | 171 (20.3%) | <0.001 (1) |

| 2b. Temperature Outcomes per Timepoint |                      |               |             |            |
|----------------------------------------|----------------------|---------------|-------------|------------|
| Timepoint                              | Temperature category | No heated cot | Heated cot  | p-value    |
| 1 (0-2h)                               | Normothermia         | 296 (71%)     | 382 (64.5%) | 0.0315 (1) |
|                                        | Hypothermia          | 78 (18.7%)    | 129 (21.8%) | 0.2320 (1) |
|                                        | Hyperthermia         | 43 (10.3%)    | 81 (13.7%)  | 0.1083 (1) |
| 2 (2-24h)                              | Normothermia         | 369 (70.8%)   | 549 (65.8%) | 0.0555 (1) |
|                                        | Hypothermia          | 136 (26.1%)   | 186 (22.3%) | 0.1097 (1) |
|                                        | Hyperthermia         | 20 (3.8%)     | 120 (14.4%) | <0.001 (1) |
| 3 (24-48h)                             | Normothermia         | 400 (81%)     | 279 (82.8%) | 0.5057 (1) |
|                                        | Hypothermia          | 51 (10.3%)    | 6 (1.8%)    | <0.001 (1) |
|                                        | Hyperthermia         | 45 (9.1%)     | 54 (16%)    | 0.0025 (1) |
| 4 (48-96h)                             | Normothermia         | 313 (80.3%)   | 58 (80.6%)  | 0.9532 (1) |
|                                        | Hypothermia          | 59 (15.1%)    | 2 (2.8%)    | 0.0045 (1) |
|                                        | Hyperthermia         | 20 (5.1%)     | 13 (18.1%)  | 0.0001 (1) |
| 5 (> 96h)                              | Normothermia         | 11 (84.6%)    | 20 (87%)    | 1.0000 (2) |
|                                        | Hypothermia          | 2 (15.4%)     | 1 (4.3%)    | 0.5394 (2) |
|                                        | Hyperthermia         | NA            | 2 (8.7%)    | 0.5254(2)  |

Statistical analyses (1) Chi-square (2) Fisher's exact test.

of skin-to-skin care, the heat mattress is built up to a maximum temperature of 40°C. At a temperature above 37.5°C, the heat mattress is reduced by 0.5°C. Temperature is measured rectally after birth and monitored every 3-4 hours for the first 24 hours of life.

In both groups infants wear disposable nappies, a cotton romper, clothing as per parents' choice and they are covered with cotton sheets and blankets. For each infant, all temperature measurements recorded during the maternity stay were included, from birth until discharge. The usual length of stay was 6–24 hours in the Dutch heated cot hospital and at least 48 hours in the Belgian control hospital.

For each infant, neonatal characteristics and temperature measurements were retrieved from the medical patient record in both centres. Temperatures were measured predominantly rectally, although the extent to which other methods were used could not be

determined from the records. The frequency of measurements followed each centre's local protocol and the nursing staff's clinical judgement, and therefore differed between the two centres.

## Statistics

### Data collection

Data were collected using REDCap (Belgium) and CTcue (IQVIA, Amsterdam, the Netherlands). Analyses were performed in R version 4.5.2. A pilot sample of 100 infants per group was used for sample size estimation, yielding a required sample of 394 infants per group at  $\alpha=0.05$  and 80% power. The final study population exceeded this target sample size, as all available eligible patients within the prespecified study period were included.

**TABLE 3:** Odds ratios (OR) for normothermia, hypothermia and hyperthermia associated with heated cot use (1 vs 0)

| Timepoint           | OR   | 95 CI interval | p-value |
|---------------------|------|----------------|---------|
| <b>Normothermia</b> |      |                |         |
| T1 (0-2h)           | 0.66 | 0.50–0.86      | 0.0024  |
| T2 (2-24h)          | 2.51 | 1.99–3.17      | <0.001  |
| T3 (24-48h)         | 2.46 | 1.75–3.47      | <0.001  |
| T4 (48-96h)         | 3.48 | 2.00–6.05      | <0.001  |
| T5 (> 96h)          | 4.52 | 0.61–33.58     | 0.14    |
| <b>Hypothermia</b>  |      |                |         |
| T1 (0-2h)           | 1.39 | 0.99-1.95      | 0.052   |
| T2 (2-24h)          | 0.27 | 0.20–0.36      | <0.001  |
| T3 (24-48h)         | 0.06 | 0.02–0.15      | <0.001  |
| T4 (48-96h)         | 0.02 | 0.004–0.097    | <0.001  |
| T5 (> 96h )         | 0.04 | 0.003–0.611    | 0.021   |
| <b>Hyperthermia</b> |      |                |         |
| T1 (0-2h)           | 1.51 | 0.96–2.37      | 0.078   |
| T2 (2-24h)          | 1.43 | 0.81–2.51      | 0.214   |
| T3 (24-48h)         | 1.01 | 0.63–1.63      | 0.958   |
| T4 (48-96h)         | 1.95 | 0.91–4.18      | 0.087   |
| T5 (> 96h )         | NA   | NA             | NA      |

Stratified by timepoint adjusted for measurement intensity per timepoint.

### Descriptive statistics

Continuous variables were non-normally distributed on Q–Q plots, so groups were compared using the Mann–Whitney U, chi-square, or Fisher’s exact test as appropriate, with significance at  $p < 0.05$ .

### Generalized Linear Mixed-Effects Model

For temperature-related outcomes, generalized linear mixed-effects models with a random intercept for each neonate were used to account for repeated measurements within patients. Heated cot use was the main fixed effect. Prespecified baseline characteristics: gestational age, birthweight, sex, mode of delivery, and birth month were evaluated as potential confounders using a change-in-estimate approach, with a change in the estimated effect of <5% considered not relevant. Maternal diabetes, 5-minute Apgar score, feeding status, and birthweight category (small, appropriate, or large for gestational age) were assessed in additional analyses. As none of these substantially changed the estimated association, they were not retained in the final models.

Timepoint was included as a categorical fixed effect in all models to account for temporal variation across t1–t5. Measurement intensity was defined as the number of temperature measurements per neonate standardized per defined time interval. Measurement intensity was included as a fixed effect in all models to account

for differences in monitoring frequency between centres and between patients, which may relate to clinical instability. Moreover, the use of a heated cot may encourage more frequent temperature assessments. Final models included heated cot use, timepoint, and measurement intensity.

### Secondary outcomes

Subgroup and interaction analyses were performed as exploratory analyses and were not adjusted for multiple comparisons. Effect modification of the association between heated cot use and normothermia, hypothermia, and hyperthermia by birthweight, gestational age, and birthweight category was assessed using likelihood ratio tests. Predicted probabilities were additionally estimated. The association between heated cot use and hypoglycaemia was evaluated at patient level using multivariable logistic regression restricted to neonates who underwent glucose monitoring, adjusted for birthweight, gestational age, sex, mode of delivery, and birth month. The effect of heated cot use on percentage postnatal weight loss was examined using multivariable linear regression among neonates with available weight-loss data, adjusted for the same baseline variables and duration of hospitalization. Sensitivity analyses included alternative definitions of hospital stay and additional adjustment for birthweight category.

## Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Jeroen Bosch Ziekenhuis (JBZ), 's-Hertogenbosch, the Netherlands (AGB code 06011034), and Algemeen Ziekenhuis Monica VZW, Belgium (enterprise number BE 0459.768.815). Due to the observational nature of the study, the Ethics Committee has waived the need for parental consent for participation in the study.

## Results

### Descriptives

We analysed 1,371 neonates: 527 in the control group and 844 in the heated cot group (Table 1). Groups were comparable for season of birth, sex, gestational age and maternal diabetes. Birthweight category differed significantly, with fewer neonates appropriate for gestational age (AGA) and more neonates large for gestational age (LGA) in the heated cot group, while proportion infants small for gestational age (SGA) were similar. Mode of delivery also differed with more Caesarean sections and fewer vaginal deliveries in the heated cot group. Apgar scores differed statistically significant only at 5 minutes, but differences were clinically small. Birthweight differed modestly between groups and feeding practices were not comparable between centres. Median hospital stay was longer in the Belgian cohort than in the Dutch cohort (64.9 vs. 25.7 hours). The number of temperature measurements were similar between centres (Table 1).

### Normothermia

The proportion of neonates classified as normothermic was significantly higher in the heated cot group than in the control group (49.1% vs. 41.9%,  $p = 0.01$ , Pearson's Chi-squared test) (Table 2). In a generalized linear mixed model adjusted for timepoint, heated cot use was associated with higher odds of normothermia (OR 1.36, 95% CI 1.18–1.58;  $p < 0.001$ ), which increased after adjustment for measurement intensity (OR 1.48, 95% CI 1.28–1.72;  $p < 0.001$ ). Measurement intensity was strongly associated with normothermia, with each one standard deviation increase in measurement intensity associated with lower odds of normothermia (OR 0.67, 95% CI 0.62–0.73;  $p < 0.001$ ). When analysed by predefined time intervals (Table 3) and adjusted for measurement intensity per timepoint, a significant interaction between heated cot use and timepoint was observed (likelihood ratio test  $\chi^2(4) = 45.88$ ,  $p < 0.001$ ). The use of a heated cot was associated with lower odds of normothermia during the first 2 hours after birth. From 2 hours onwards, the association became positive and increased over time. Beyond 96 hours, the point estimate remained elevated, but with wide confidence intervals, reflecting limited data in this interval. Inclusion of baseline covariates within the first

timepoint did not substantially change the estimated odds ratio for heated cot use.

### Hypothermia

Hypothermia occurred more frequently in the non-heated cot group than in the heated cot group (45.5% vs. 31.8%,  $p < 0.001$ ). Both mild (25.8% vs. 16.5%,  $p < 0.001$ ) and moderate hypothermia (19.7% vs. 15.3%,  $p = 0.038$ ) were less common with heated cot use (Table 2). The highest proportion of hypothermia occurred between 2–24 hours of age (Figure 2). A generalized linear mixed model adjusted for timepoint and measurement intensity showed that heated cot use was associated with lower odds of hypothermia (OR 0.51, 95% CI 0.42–0.63;  $p < 0.001$ ). Adding measurement intensity improved model fit (likelihood ratio test  $\chi^2(1) = 22.59$ ,  $p < 0.001$ ). The association was strongly time-dependent (likelihood ratio test  $\chi^2(4) = 120.7$ ,  $p < 0.001$ ), although hypothermia odds at the first timepoint were paradoxically higher in the heated cot group, heated cot use was associated with consistently lower odds from timepoint 2 onward, with the strongest reduction at timepoint 4 (Table 3).

### Hyperthermia

Hyperthermia was more frequent in the heated cot group than in the non-heated group (26.8% vs. 20.9%,  $p = 0.013$ ), including both mild and moderate cases (Table 2). Heated cot use was associated with increased odds of hyperthermia (OR 1.72, 95% CI 1.28–2.31,  $p < 0.001$ ). Adding timepoint and measurement intensity to the model significantly improved fit (likelihood-ratio test,  $\chi^2(5) = 176.04$ ,  $p < 0.001$ ). There was no significant interaction between heated cot use and timepoint (likelihood-ratio test,  $\chi^2(4) = 7.98$ ,  $p = 0.09$ ), indicating that the effect of heated cot use did not differ significantly across timepoints. In a sensitivity analysis adjusting for timepoint-specific measurement intensity, the per-timepoint odds ratios were attenuated and no longer reached statistical significance at any timepoint, although all point estimates remained in the same direction (OR  $\geq 1$ ). Estimates at timepoint 5 were unstable across all models, consistent with sparse data (Table 3).

### Outcomes by birthweight, gestational age and birthweight category

No significant interaction was observed between heated cot use and either gestational age or birthweight for normothermia, hypothermia, or hyperthermia. For gestational age, likelihood ratio tests showed no evidence of effect modification for normothermia ( $\chi^2 = 0.12$ ,  $p = 0.73$ ), hypothermia ( $\chi^2 = 0.044$ ,  $p = 0.83$ ), or hyperthermia ( $\chi^2 = 0.03$ ,  $p = 0.86$ ). Similarly, birthweight did not significantly modify the association between heated cot use and normothermia ( $\chi^2 = 1.76$ ,  $p = 0.18$ ), hypothermia ( $\chi^2 = 0.35$ ,  $p = 0.55$ ), or hyperthermia ( $\chi^2 = 0.26$ ,  $p = 0.61$ ). Predicted probabilities nevertheless

suggested a greater absolute benefit of heated cot use for normothermia at lower birthweight and lower gestational age. For hypothermia, predicted probabilities were lower in the heated cot group across the birthweight and gestational age ranges, with a visually larger absolute difference at lower birthweight. For hyperthermia, predicted probabilities were consistently higher in the heated cot group, with visually steeper increases at higher birthweight and gestational age.

In contrast, birthweight category (SGA/LGA/AGA) significantly modified the association between heated cot use and both normothermia ( $\chi^2 = 6.19$ ,  $p = 0.045$ ) and hypothermia ( $\chi^2 = 8.20$ ,  $p = 0.017$ ), but not hyperthermia ( $\chi^2 = 5.22$ ,  $p = 0.074$ ). For normothermia, the association with heated cot use was significant only in SGA neonates. For hypothermia, lower odds were observed across all birthweight categories, with the strongest associations in LGA and SGA neonates (Figures 3–4).

### Exploratory clinical outcomes

Glucose monitoring was performed more frequently in the heated cot group than in the standard care group (38.0% vs. 12.7%). Among neonates who underwent glucose measurement, the proportion with hypoglycaemia did not differ significantly between groups (123/321 [38.3%] vs. 18/67 [26.9%];  $p = 0.103$ ). In multivariable analysis, heated cot use was not significantly associated with hypoglycaemia (OR 1.70, 95% CI 0.87–3.30;  $p = 0.118$ ), while it was strongly associated with a higher probability of glucose monitoring. Data on weight loss were less complete in the heated cot group than in the standard care group (40.5% vs. 97.0%). Median weight loss was lower in the heated cot group (5.07%, IQR 3.81–6.42) than in the standard care group (6.25%, IQR 5.06–7.71;  $p < 0.001$ ). After adjustment for hospitalisation duration and baseline characteristics, heated cot use remained associated with lower weight loss (mean difference  $-0.88$  percentage points, 95% CI  $-1.31$  to  $-0.46$ ;  $p < 0.001$ ).

## Discussion

This multicentre study compared thermoregulation in healthy term neonates nursed on heated versus standard cots. Heated cot use was associated with improved early postnatal thermoregulation; higher odds of normothermia, lower odds of hypothermia, but also with higher odds of hyperthermia. Trends toward favourable association were observed in vulnerable subgroups, such as lower gestational age, lower birth weight and SGA neonates.

The high burden of hypothermia underscores this relevance: overall hypothermia incidence (37%) exceeded studies using the same WHO definition (21%–23%) (8,19). Higher rates (28.4%–52.5%) rely on unclear definitions (2,18). Interpretation is complicated because measurements per neonate are rarely reported.

We found higher measurement intensity associated with higher incidence: the first study, to our knowledge, to account for this.

### Association between heated cot and temperature maintenance

The effect of heated cot use varied over time. Early after birth, it was associated with lower rates of normothermia, likely reflecting the transitional physiological instability of this period, the shorter duration and fewer measurements at timepoint 1, and more frequent skin-to-skin care that reduced thermal differences between groups (18). From two hours onwards, the association became progressively positive, with increasing odds of normothermia and decreasing odds of hypothermia. This pattern persisted after adjustment for measurement intensity, indicating it cannot be fully explained by differential monitoring.

### Heated Cot Use and Increased Risk of Hyperthermia

Heated cot use was associated with significantly higher odds of hyperthermia. This effect was also time-dependent, with the highest odds at timepoints 1 and 2. In subgroup analyses, the effect appeared more pronounced at higher gestational age and birthweight, although the interaction terms were not significant. Nevertheless, significantly higher odds were observed in the AGA and LGA subgroups. Tveiten et al. similarly reported increased hyperthermia risk from 8 hours of age and in neonates with higher birth weight (18). These findings suggest that heated cot use in otherwise healthy newborns requires careful monitoring and may not be the optimal for this subgroup.

### Heated Cot Use in Neonates with Increased Risk of Hypothermia

The effect of heated cots was more pronounced at lower gestational age and birth weight. SGA neonates in the heated cot group showed significantly higher normothermia and lower hypothermia, while effects in AGA and LGA were smaller or non-significant. Heated cots may be especially beneficial in high-risk subgroups prone to hypothermia (18,19).

### Heated Cot Use and Early Neonatal Outcomes

As hypothermia is strongly associated with hypoglycaemia, effective temperature maintenance might be expected to reduce hypoglycaemia (8, 20). However, this study found no evidence that heated cot use was independently associated with less hypoglycaemia among neonates undergoing glucose monitoring. The unadjusted likely reflects more protocol-driven glucose measurements in the study cohort versus clinically guided monitoring in controls indicating detection bias. Heated cots were consistently associated with reduced weight loss, even after adjusting

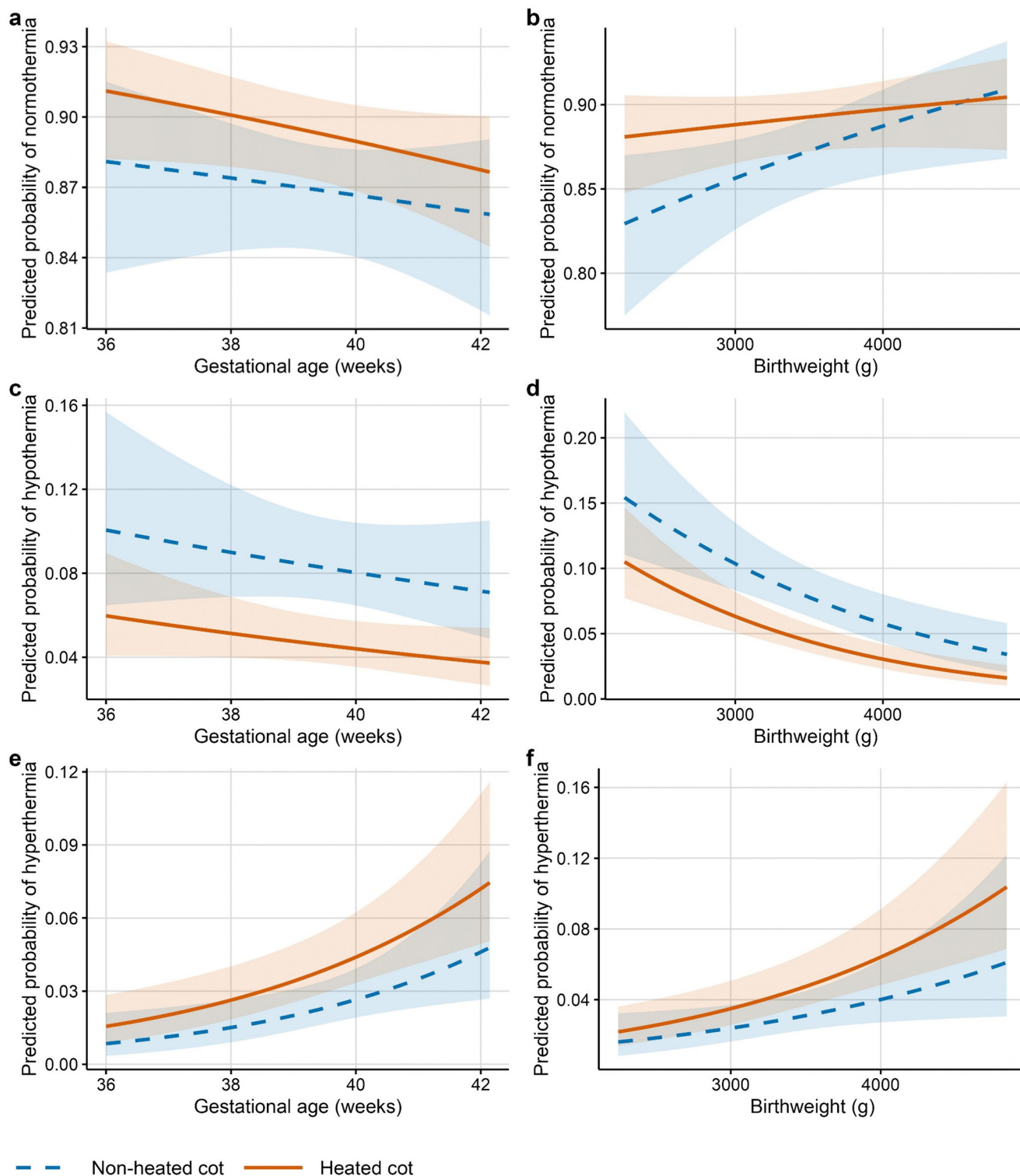


**FIGURE 3:** Predicted probability of normothermia (a, b), hypothermia (b, c) and hyperthermia (d, e) by gestational age, stratified by heated cot use. Predictions are derived from a generalized linear mixed model and adjusted for timepoint and measurement intensity to allow comparison at equal monitoring levels. Solid red line = heated cot group, Dashed blue line = non-heated cot group.

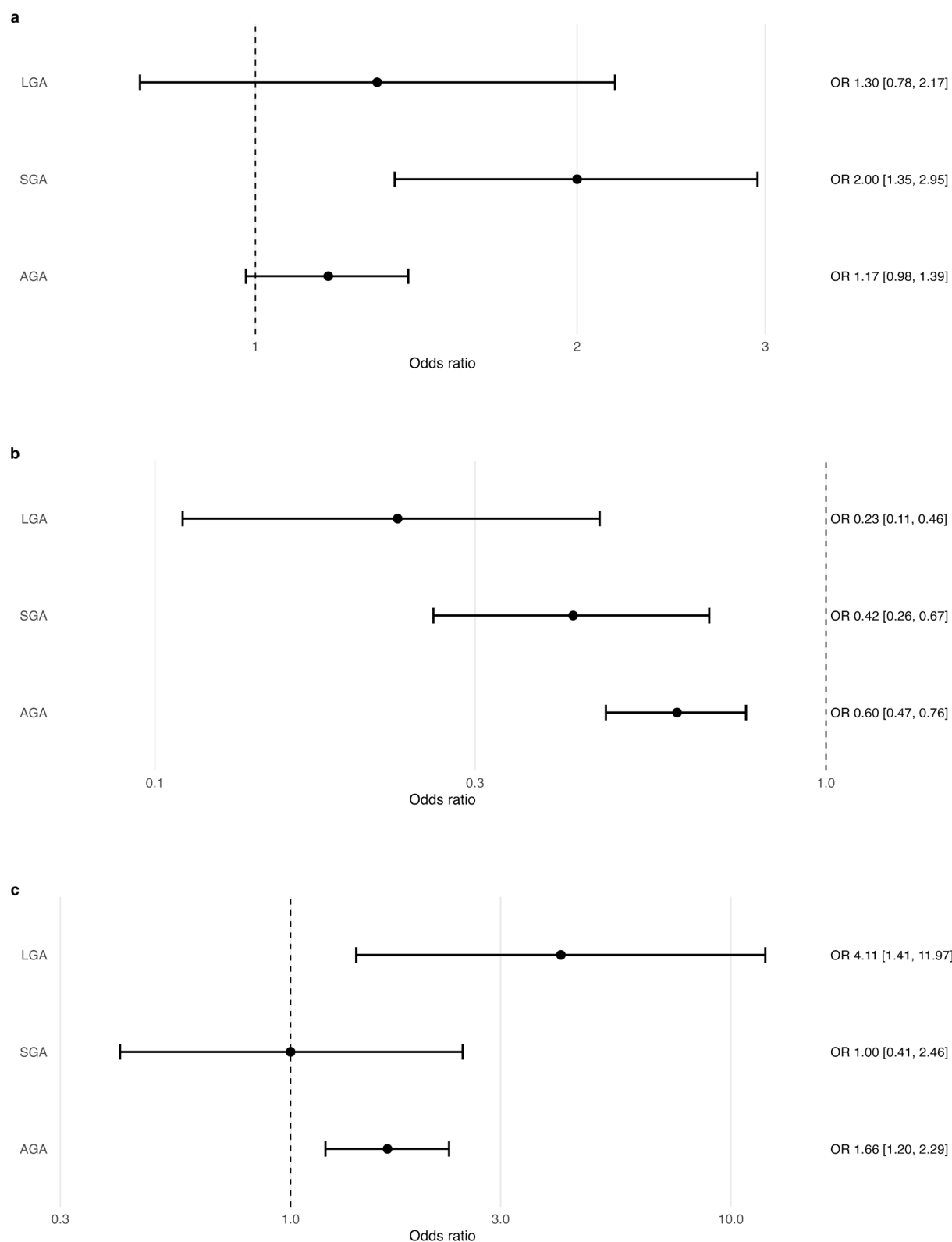


**FIGURE 4:** Forest plot with effect of heated cot versus no heated cot on birthweight categories regarding normothermia (a), hypothermia (b) and hyperthermia (c). Adjusted for mean timepoint and mean measurement intensity. Odds ratio with 95% confidence intervals are added. LGA: large for gestational age, SGA: small for gestational age, AGA: appropriate for gestational age.

for gestational age, birth weight, and hospitalization duration. This should be interpreted with caution, as the groups differed substantially in protocol-driven length of hospital stay. Further research is needed to determine clinical relevance beyond the early neonatal period.

### Limitations

Several limitations should be acknowledged. First, the retrospective observational design limits causal inference, and subgroup analyses were exploratory and potentially underpowered, particularly for smaller categories. Second, although the cohorts were largely comparable, some differences should be acknowledged. The difference in birth weight reached significance but appears of limited clinical relevance, whereas the differences in AGA/LGA proportions are relevant, as LGA neonates may be intrinsically more prone to hyperthermia and SGA neonates to hypothermia (4,6,7,13,14,18,19). Third, the centres differed organisationally in ways for which adjustment was not possible: a higher proportion of home births and selective referral of higher-risk neonates in the Netherlands, combined with restricted chart availability for lower-risk births. The observed differences in mode of delivery are consistent with this, and residual selection bias cannot be excluded.

Thermoregulatory strategies were centre-specific and applied to all neonates independent of risk factors; consequently, heated cot exposure coincided with institutional and protocol variations. The two centres also differed in their thermal management protocols, as the heated cot centre prescribed more frequent measurements during the first 24 hours than the control centre. Despite a similar total number of measurements per patient, the marked difference in length of stay may therefore have affected the timing, distribution and intensity of monitoring. The heated cot centre was accompanied by a more intensive monitoring regimen, which may have heightened staff awareness of thermal care and prompted earlier intervention. A further methodological consideration is measurement intensity: neonates with more frequent temperature measurements have a higher probability of being classified as hypo- or hyperthermic. By accounting for repeated measurements within neonates and adjusting for measurement intensity, our analysis aimed to reduce this detection bias.

Finally, some data limitations restrict interpretation: glucose monitoring was not uniform, limiting hypoglycaemia comparisons, and weight loss data were incomplete, particularly in the heated cot group. Additionally, data on potentially relevant determinants of neonatal thermoregulation e.g. clothing, skin-to-skin contact, maternal temperature, epidural analgesia, and ethnicity, were unavailable. Room temperature may have been especially relevant, as it was adjustable according to parental preference but not recorded.

## Conclusion

This multicentre study suggests that heated cot use is associated with improved thermal control compared with standard care, reflected by higher odds of normothermia and lower odds of hypothermia, but also by higher odds of hyperthermia. At the subgroup level, this favourable effect appeared most pronounced in SGA neonates, whereas heated cot care may be less suitable for LGA neonates, who appear more prone to hyperthermia. Findings on hypoglycaemia were inconclusive reflecting differing glucose monitoring practices, and the apparent reduction in weight loss should be interpreted cautiously given the substantially shorter, protocol-driven hospital stay in the heated cot group. Heated cot use was associated with a statistically and potentially clinically relevant improvement in thermoregulation. Routine implementation for the overall population does not appear justified based on this study alone, but targeted use in subgroups at increased risk of hypothermia, including SGA, low birth weight, and late preterm neonates, may offer added value, though this remains uncertain. Prospective studies, ideally randomized controlled trials, are warranted to confirm these findings, clarify metabolic and clinical effects, examine temporal temperature variability, and optimize thermal management protocols in routine neonatal care.

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*Consent to Participate:* Due to the observational nature of the study, the Ethics Committee has waived the need for parental consent for participation in the study

*Use of Artificial Intelligence:* Artificial intelligence tool (ChatGPT, open AI, version 5.4) was used exclusively for linguistic support, including improvement of grammar, wording, and readability. All study design decisions, analyses, interpretation of findings, and conclusions were made by the authors. The authors assume full responsibility for the final content of the manuscript.

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