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Unlike Kangaroo care, mechanically simulated Kangaroo care does not change heart rate variability in preterm neonates☆

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ARTICLE INFO

ABSTRACT

Background: While numerous positive effects of Kangaroo care (KC) have been reported, the duration that parents can spend kangarooing is often limited.

Aim: To investigate whether a mattress that aims to mimic breathing motion and the sounds of heartbeats (BabyBe GMBH, Stuttgart, Germany) can simulate aspects of KC in preterm infants as measured by features of heart rate variability (HRV).

Methods: A within-subject study design was employed in which every routine KC session was followed by a BabyBe (BB) session, with a washout period of at least 2 h in between. Nurses annotated the start and end times of KC and BB sessions. Data from the pre-KC, KC, post-KC, pre-BB, BB and post-BB were retrieved from the patient monitor via a data warehouse. Five time-domain features of HRV were used to compare both types of intervention. Two of these features, the percentage of decelerations (pDec) and the standard deviation of decelerations (SDDec), were developed in a previous study to capture the contribution of transient heart rate decelerations to HRV, a measure of regulatory instability.

Results: A total of 182 KC and 180 BabyBe sessions were analyzed in 20 preterm infants. Overall, HRV decreased during KC and after KC. Two of the five features showed a decrease during KC, and all features decreased in the post-KC period ($p \leq 0.01$). The BB mattress as employed in this study did not affect HRV.

Conclusion: Unlike KC, a mattress that attempts to mimic breathing motion and heartbeat sounds does not affect HRV of preterm infants.

1. Introduction

Kangaroo care (KC) refers to a period in which a diaper-clad infant is lying prone on a naked caregiver's chest, in direct skin-to-skin contact. It is a frequently used intervention in preterm infants since it reduces morbidity and mortality and is safe, even in infants who are born very prematurely [1]. KC is associated with multiple physiological benefits such as improved regulation of temperature and sleep [2–5].

Previous research demonstrated that features of heart rate variability (HRV) could capture regulatory changes taking place during KC [6]. HRV reflects the dynamic, rapidly occurring changes in autonomic regulation caused by the primary physiological systems controlling the heart rate – the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS). These neuronal pathways can

modulate heart rate from one beat to another in response to environmental changes [7,8]. In preterm infants, this beat-to-beat variability decreases during KC, owing to a decrease in the magnitude of transient heart rate decelerations, a feature reflective of regulatory instability [6]. In other words, in preterm infants, KC improves regulation despite their physiologically immature autonomic nervous system.

To enhance KC, hospitals strive to increase kangarooing by coaching parents about its importance [9]. Also, the industry aims to develop devices intended for facilitating, augmenting and simulating aspects of KC. Examples of these potentially include KC chairs, KC vests, and products using parental or familiar scents and those that generate biological sounds, as well as mattresses that can generate breathing-like motion [10]. In theory, such devices, aiming to simulate aspects of KC can play a role in improving regulation in preterm infants. Such devices might be especially important when parents are unable to spend sufficient time kangarooing, for various reasons, for instance, due to long distances from home to hospital and limited parental leave after birth, or back-to-work obligations [11]. While it is well accepted that decreasing exposure of neonates to noxious stimuli such as handling, light, and noise improves outcomes [12], at present, there is insufficient evidence to suggest that stimuli reminiscent of parental presence or the fetal environment are beneficial and should be incorporated into routine clinical practice [10]. However, as devices using such stimuli become more commonly available, formal quantitative and qualitative analyses will be required to ascertain their usefulness in improving neonatal care.

One such CE-certified device is the BabyBe (BabyBe GMBH, Stuttgart, Germany), a mattress that aims to mimic the sounds of heartbeats and the motion of a breathing chest [13]. Since HRV predictably responds to KC, we conducted a study to investigate whether the BabyBe can simulate KC as measured by features of HRV.

2. Method

Clinically stable preterm infants, born between 26 and 34 weeks gestational age and admitted to the neonatal intensive care unit (NICU) of Máxima Medical Centre from October 2016–March 2017 were incorporated into the study at the earliest suitable occasion after admission. Exclusion criteria were any serious clinical conditions at the time of inclusion (e.g., sepsis, necrotizing enterocolitis), conditions that interfered with breathing (mechanical ventilation), and severe brain pathology (intraventricular haemorrhage grade III/IV or cystic periventricular leukomalacia). Since, aside from providing an alternative (CE-certified) mattress, the study was of an observational nature, the medical ethical committee provided a waiver in accordance with the Dutch law on medical research with humans (WMO). Written informed consent was obtained from parents for allowing their baby to be cared for on a BabyBe mattress. Table 1 characterizes the study participants.

For infants who were included in the study, the routine mattress was

Table 1
Patient characteristics at birth and on the days corresponding to intervention (KC and BabyBe).

Characteristics	Median	25th percentile	75th percentile
Gestational age (weeks)	29.0	27.6	30.6
Birth weight (g)	1267	1030	1437
No. of KC sessions in each infant	9	5.5	11
Duration of KC sessions (min)	100	81	124
PMA during first KC session (weeks)	30.6	29.8	31.4
PMA for all KC sessions (weeks)	31.3	30.6	32.0
Postnatal age during KC (days)	11	5.5	26
Duration of data collection period (days)[a]	6	4.5	10.5

Legend: Abbreviations: KC, Kangaroo care; PMA, Post menstrual age.
[a] Defined as the number of days between the first and the last days of the intervention.

Fig. 1. The BabyBe mattress.
The BabyBe mattress has two incorporated lung-like air bladders for mimicking chest motion and one smaller, round air bladder in the middle for mimicking heartbeat sounds. The air bladders are attached to two tubes (one for the two lung-shaped air bladders (blue) and one for the round air bladder (white)) that exit the mattress to be connected to the control module which is responsible for inflating and deflating the bladders at the right pace. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

replaced by the BB mattress (shown in Fig. 1) for the entire duration of the study. The BB mattress is a medical device (class 1) that attempts to simulate breathing motion and the sounds of heartbeats passively by periodically inflating air bladders that are incorporated within the mattress [13]. For simulating breathing, two lung-shaped air bladders are sinusoidally inflated at a rate of 13 cycles per minute, corresponding to the typical breathing rate of an adult at rest. For the heartbeats, an air bladder (in between the lung-shaped air bladders) is biphasically inflated and deflated at a frequency of 68 cycles per minute to mimic the lub-dubb sounds of a heartbeat (57 dB). Notably, the inflation of this air bladder is audible but not palpable. When the mattress is switched off, it does not move nor sound. The mattress was only switched on during the periods of intended use after KC.

Since KC visibly changes HRV, we designed a study to explore whether the simulation of parental presence by the BB mattress exerts a similar effect. Nurses were asked to switch on the BB mattress 2 after every KC session. This washout period of 2 h allows for any lasting effect of KC to wear off. Since, on average, KC sessions in our unit are approximately 90 min long, nurses were asked to leave the BB mattress on for 90 min as well. For every KC and BB-session, nurses annotated the start and end-times. This within-subject design controlled for inter-individual differences in HRV due to for instance gender, gestational age and postmenstrual age. Each infant was included in the study until approximately 10 KC and BabyBe sessions were obtained, which on average took a week.

As is also described in a previous publication, all KC sessions that were shorter than 60 min were excluded from the analysis since a 30-minute stable period was required during KC for statistical comparisons and to reduce effects of transfers from and to the incubator [6]. Similarly, BB sessions that were shorter than 60 min or which started within 2 h of the last KC-session were excluded. All patient monitor data,
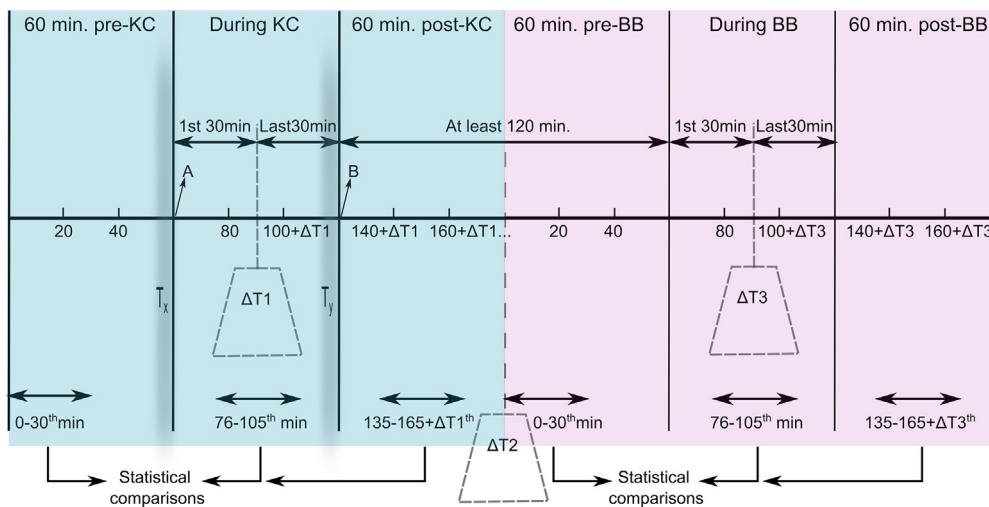
Fig. 2. An illustration of the methodology. The blue square illustrates the period related to Kangaroo care (KC), the pink square illustrates the period related to the BabyBe (BB) session. The pre-KC, post-KC, pre-BabyBe (BB) and post-BB sessions are 60 min long. The duration of KC and BB sessions can vary (first 30 min + ΔT1 or ΔT3 + last 30 min) and therefore the first 30 and last 30 min are used for visualization. The period between the end of the KC period and the onset of the BabyBe is at least 120 min, but this can also vary (ΔT2). Tx and Ty represent the time to transfer the baby from the incubator to parental chest and vice versa. A refers to the first minute on the parent's chest, B to the first minute back in the incubator. ×1 equals 200 min + ΔT1 + ΔT2, ×2 equals 220 min + ΔT1 + ΔT2 and so on. The first 30 min of the pre-intervention periods and the 16th to 45th minute of during and post-intervention periods, corresponding to 76th to 105th and the 135 + ΔT1–165 + ΔT1 minutes of data are used as stable epochs for statistical comparisons. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

including the electrocardiography (ECG) waveform sampled at 250 Hz, were automatically logged in a data warehouse (PIIC iX, Data Warehouse Connect, Philips Medical Systems, Andover, MA) from which it was retrospectively extracted for analysis.

To observe regulatory changes in infants as a result of the intervention, be it KC or stimulation by the BB mattress, ECG waveforms were retrieved from the data warehouse for three periods: the 60 min before the intervention, the period of intervention and 60 min after the intervention. From this data, features of HRV were extracted, which are graphically displayed and statistically analyzed, as shown in Fig. 2 and Tables 2 and 3. Since nursing care often occurs immediately before KC, the first 30 min of the pre-KC period is considered to be a representative, stable or nascent period. This 30-min epoch is compared to a stable 30-minute epoch during KC, defined as the 16–45th minute of KC – corresponding to the 75–105th minute of data in the timeline. Since even for the shortest KC sessions (60 min), the start and end time of this KC-epoch are 15 min away from the transition from the incubator to the parental chest and vice versa, this epoch is considered stable. A detailed discussion motivating this choice is provided elsewhere [6]. The stable 30-minute epoch in the pre-KC period is also compared to a 30-minute epoch in the post-KC period. This epoch was chosen to be the 16–45th minute of the post-KC period, also to minimalise any effects of the transition from the parental chest to the incubator. For the BB intervention, equivalent epochs were chosen (Fig. 2). However, it should be noted that since this was an observational study, no restraints were placed on the timings of nursing care and therefore these did not necessarily occur in the 30 min before the mattress was switched on.

Similar to a previous study, the mean and standard error of the mean (SEM) for features of HRV were calculated every minute using a sliding window of 5 min from all data corresponding to KC and BB

sessions respectively. Normalization was performed by subtracting the mean value of each feature in the first 30 min of the pre-KC and pre-BB periods respectively from the duration of the corresponding recording, as detailed elsewhere [6]. Additionally, the baseline heart rate defined as the mean value of the heart rate in the first 30 min of the pre-KC and the pre-BB periods were calculated.

In the current study, we used five time domain features of HRV – the standard deviation of the NN-intervals (SDNN), the root mean square of the successive differences (RMSSD), the percentage of NN-interval differences larger than 50 ms (pNN50), the percentage of transient decelerations (pDec), and the standard deviation of decelerations (SDDec) [6]. A brief description of these features is presented in Table 2. For a more detailed description, we refer to Kommers et al. 2017 [6].

2.1. Statistical analyses

All KC and BB sessions are considered separate events and differences between pre-intervention, intervention and post-intervention periods are determined for all HRV-features. The median and interquartile ranges (IQR) for the mean values of the HRV features corresponding to the stable 30-minute epochs in the pre-intervention, intervention, and post-intervention periods for both KC and BabyBe were calculated. The baseline heartrates for the pre-KC and the pre-BB interventions were described using median (IQR) as well. Statistical comparisons were performed between the pre-intervention and during intervention epochs, as well as the pre-intervention and post-intervention epochs, using the two-sided paired Wilcoxon signed-rank tests. A p-value ≤0.01 was considered significant. The choice for using median (IQR) values for HRV and the Wilcoxon test for statistical comparisons were based on the fact that the underlying data were not necessarily normally distributed.

Table 2
Statistical testing and HRV values for the stable 30-minute epochs of the pre-KC, during-KC and post-KC periods (median, [IQR]).

HRV-feature	Implication	Pre-KC period	During KC period	p-value*	Post-KC period	p-value**
SDNN (ms)	Overall variability	21 [15–30]	18 [12–25]	0.0009	18 [13–24]	0.0005
RMSSD (ms)	High-freq variations	10 [6–19]	8 [5–14]	0.0166	8 [5–13]	0.0001
pNN50 (%)	High-freq variations	0.42 [0.14–1.5]	0.36 [0.12–1.2]	0.74	0.32 [0.10–0.96]	0.01
pDec (%)	%Decel in HR	45 [40–50]	46 [40–50]	0.90	47 [42–51]	0.006
SDDec (ms)	Extent of decel in HR	21 [12–38]	17 [10−30]	0.0008	16 [10–27]	0.0018

Abbreviations: freq, frequency; decel, decelerations; HR, heart rate.
  * Comparing pre and during KC periods.
  ** Comparing pre and post KC periods.

Table 3

Statistical testing and HRV values for the stable 30-minute epochs of the pre-BB, during-BB and post-BB periods (median, [IQR]).

HRV-feature	Implication	Pre-BB period	During BB period	*p*-value*	Post-BB period	*p*-value**
SDNN (ms)	Overall variability	21 [15–30]	21 [14–30]	0.17	21 [15–28]	0.14
RMSSD (ms)	High-freq variations	9 [6–19]	9 [6–18]	0.82	10 [6–20]	0.39
pNN50 (%)	High-freq variations	0.37 [0.14–1.27]	0.41 [0.17–1.29]	0.36	0.59 [0.21–1.5]	0.26
pDec (%)	%Decel in HR	46 [41–50]	45 [40–50]	0.41	45 [41–50]	0.43
SDDec (ms)	Extent of decel in HR	20 [12–39]	21 [11–37]	0.77	19 [13–37]	0.38

Abbreviations: freq, frequency; decel, decelerations; HR, heart rate.

* Comparing pre and during BB periods.

** Comparing pre and post BB periods.

3. Results

A total of 182 KC and 180 BabyBe sessions were obtained from 20 preterm infants. The dynamically occurring changes in HRV in response to KC and the BB mattress are shown in Fig. 3 using four features. The RMSSD is not shown due to its theoretical overlap with the pNN50, as described in Tables 2 and 3.

During KC, a decrease in SDNN and SDDec can be observed, and these values remain low in the post-KC period as well. Also, in the post-KC period the pNN50 is lower than in the pre- and during KC periods. Results of statistical analysis are shown in Table 2 and indicate that these changes are statistically significant. Two of the five features, the SDNN and the SDDec, showed a decrease between the pre-KC and KC period. All features showed a statistically significant change between the pre-KC and post-KC periods. In all features, except pDec, this change corresponded to a decrease.

During BB sessions the overall HRV reflected by the SDNN, and the instability of autonomic nervous system regulation reflected by the SDDec show a downward trend (Fig. 3), but this trend was not statistically significant (Table 3). None of the features showed a statistically significant change between the pre-BB and BB epochs or between the pre-BB and post-BB epochs. In summary, unlike KC, simulated KC using the BB mattress did not affect HRV. Of note is that the median (IQR) values of the baseline heart rates corresponding to the pre-KC and the pre-BB groups were very similar, 161.4 (154.5–166.9) and 163.9 (155.2–169.8) bpm respectively.

HRV features changed notably during the transfer periods from the incubator to the parent's chest and vice versa. In contrast, merely switching the BabyBe mattress on and off did not change HRV (Fig. 3). Furthermore, during the periods infants were being kangarooed or the BB mattress was used, routine feeding took place in 110 out of 182 and 79 out of 180 sessions respectively. Routine nurse handling did not occur during KC but occurred during 44 BB sessions as indicated with encircling the same on study forms. Exact timings were not annotated and, due to the observational nature of the study, non-deterministic with regard to the onset of the BB mattress.

4. Discussion

In this study, we analyzed the effect of using a mattress that aims to simulate breathing motion and mimic the sound of heartbeats (BabyBe GMBH, Stuttgart, Germany) using features of HRV. We compared the effect of using this mattress and contrasted it with KC in 20 preterm infants. In total, 182 KC sessions and 180 BB sessions were analyzed using five-time domain HRV features — SDNN, RMSSD, pNN50, pDec, and SDDec. As in a previous study, HRV decreased during and after KC [6]. However, unlike KC, the BB mattress did not affect HRV.

Kangaroo care, a comfortable period for both infant and parent, represents a state of improved regulation in preterm infants [2,3,5,6]. The easily reproducible nature of KC makes it a natural, controlled setting for studying how HRV responds to this intervention. As previously described, it is remarkable that HRV decreases as a result of KC, given that in adults a decrease in HRV is associated with greater cardiovascular morbidity and mortality [8]. Along the lines of Porges' Polyvagal theory, it was speculated that different neural mechanisms responsible for regulating the neurobehavioral state to deal with environmental challenges could explain this phenomenon [14]. The Polyvagal Theory states that the PSNS comprises of two evolutionarily and functionally different subsystems, a primitive unmyelinated system, and a newer, uniquely mammalian, myelinated system [15]. In addition to the SNS, these two sub-systems of the PSNS are essential for autonomic regulation. The SNS generates a 'fight or flight' response, while the uniquely mammalian branch of the PSNS responds to challenges by inhibiting SNS activity. The primitive branches of the PSNS respond to challenges with immobilisation and freezing of regulatory systems. We speculated that the high baseline HRV in preterm infants (pre-KC, pre-BB periods) is a result of their unique physiology, where the SNS and primitive PSNS are dominant, resulting in regulatory instability including large variations in heart rate. KC and associated parental co-regulation seem to trigger an immediate transition towards the more stable regulation offered by the myelinated vagus [6]. The regulation offered by this branch of the PSNS encourages efficient usage of energy and rapid regulation of cardiac output [14,15]. Two specific features (pDec and SDDec) were used to test the hypothesis whether cardiac regulation improves during KC by quantifying the contribution of transient heart rate decelerations to HRV [6]. These features, reflective of regulatory instability, indeed decreased in response to KC.

In comparison with a previous study, the decrease in HRV during KC was less pronounced in the current study [6]. However, despite being more modest, the decrease was attributable to a decrease in SDDec, indicating increased regulatory stability during KC. We assume that this difference is due to the higher age of the infants that participated in this study (on average more than two weeks older and over 300 g heavier at study participation). Since more mature infants are likely to have a better developed PSNS, they seem to present with lower baseline regulatory instability in the first place (median (IQR) values of SDDec were 60 ms (26–157) versus 21 ms (12–38)).

Even though the SDDec seems to decrease consistently over the course of kangarooing, the SDNN and pNN50 remain stable. This stability could be a reflection of the contribution of "healthy" variation to the overall HRV (as is seen in adults when the PSNS is dominant) generated by a more mature myelinated PSNS regulation in this population. Evidence of vagal maturation with increasing PMA has frequently been reported, especially between 30 and 40 weeks of age [16–18].

In agreement with previous findings, these effects of parental co-regulation persist during the post-KC period. In fact, in the current study, the decrease in HRV is most pronounced post-KC. This finding is a natural consequence of the above – post-KC the HRV reduces further because the contribution of healthy variation to the overall HRV ceases, while the contribution due to regulatory instability is still lower than in the pre-KC period due to a lasting effect of improved regulation.

As opposed to the comfortable period of KC, the BB sessions did not affect HRV. We reasoned that this could be due to dampening of the stimuli provided by the mattress. Bed sheets and positioning materials that are placed over the mattress potentially dampen the motion and

Fig. 3. Time series of four HRV features during KC sessions (left) and BabyBe sessions (right). Normalized mean ± SEM values are shown for the pre-intervention periods (0–59 min), the first 30 min of the intervention period (60–89 min), the last 30 min of the intervention period (90–119 min), and the post-intervention period (120–180 min). The y-axes represent normalized values of the SDNN (A1 + A2), pNN50 (B1 + B2), SDDec (C1 + C2) and pDec (D1 + D2). Note that the RMSSD is not shown due to its overlap with the pNN50 and SDDec precedes pDec to enhance the comparability of the time series.

sound, which competes with other environmental noise such as ventilator devices. We did not measure either stimuli within the incubator. It is, therefore, possible that infants never got a recognizable dose of either stimulus. However, such a set up would be typical for the use of these devices in clinical practice.

Moreover, even if the breathing motions were felt and the simulated sounds of heartbeats were heard, infants might not associate the inanimate, static and repetitive stimuli with their biological counterparts which are a more complex, dynamic and potentially synchronous interaction between the parent and the infant. In other words, KC is a dynamic, multisensory experience and chest motion and heartbeat sounds are only two of the numerous stimuli provided during KC [19,20]. Other stimuli, such as tactile, vocal, visual and olfactory stimulation like gentle touch, body heat, speech, breathing sounds, contours, body scent and potentially the taste or smell of breast milk are absent in the BB mattress [21–25]. Individually, research has shown positive influences of all these stimuli on preterm infants [25–29], but those effects are not as large as when the stimuli are combined during KC [2,3,5]. This might be because, during KC, these separate, dynamic and reciprocal stimuli amplify each other's positive effect [30–33].

Other limitations should be taken into account as well. Due to the observational nature of this study, feeding routinely took place during both BB and KC periods. Nurse handling, while not performed during KC occurred during BB sessions. Also, the precision of nurse annotations for the start and end time had a resolution of 1–2 min (and not seconds). Finally, during BB sessions, babies were positioned according to routine caregiving, which in our NICU entails both prone or lateral positioning and regular re-positioning, whereas, during KC, babies are always in the prone position. Nonetheless, the effect of KC on HRV remained in the post-KC period, during which babies were also positioned according to routine caregiving. Overall HRV offers a non-invasive, easy to use set of metrics to track autonomic regulation. The KC setting provides a controlled and reproducible background to contrast the effect on HRV due to a device mechanically simulating KC. This method of using HRV offers a low threshold for use, and a scientific approach to determine the effectiveness of new interventions in the NICU, interventions which, while beneficial, may not affect traditional study outcomes such as weight gain, length of stay etc. that require the mounting of large and expensive clinical studies.

5. Conclusion

In this study, we used features of HRV to compare changes in the autonomic regulation of preterm infants as a result of KC, and of a mattress that attempts to mimic breathing motion and heartbeat sounds (BabyBe GMBH, Stuttgart, Germany), two aspects of KC. HRV decreased in response to KC, but not in response to the mattress. Such an approach of using HRV can help determine the effectiveness of devices that are developed with the intent of improving neonatal care giving. In addition, it can help investigate differences in physiological responses of infants to different clinical interventions.

Acknowledgement

Conflict of interest

The authors have no conflict of interest to declare.

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