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CLINICAL RESEARCH ARTICLE

Effects of semi-upright swings on vital signs in NICU infants

Suhagi Kadakia[1,2], Amal Isaiah[2,3,4] and Dina El-Metwally[1,2]✉

BACKGROUND: The aim of this study was to compare the impact of a semi-upright swing with a standard crib on vital signs in infants in the neonatal intensive care unit (NICU).
METHODS: We performed a within-subjects' comparison of vital signs of NICU infants corrected to ≥34 weeks of gestation and placed in the supine position versus the semi-upright position in a swing. The primary outcome was the mean oxygen saturation, and the secondary outcomes were the mean heart rate, the proportion of time with oxygen saturation (SpO_2) <90%, and respiratory rate.
RESULTS: Of the 65 infants, 34 (57%) were male and 32 (50%) were black. The mean ± SD gestational age at birth was 32.4 ± 5.1 weeks. In all, 40% were on noninvasive respiratory support. There were no significant differences in oxygen saturation, heart rate, time with oxygen desaturation defined by $SpO_2 < 90\%$, or respiratory rate between the supine and semi-upright positions. A higher risk of desaturations was observed in infants without respiratory support (RR, 1.24, 95% CI, 1.15–1.33) and low-birth-weight infants (RR, 1.55, 95% CI, 1.42–1.69).
CONCLUSIONS: The placement of infants in a semi-upright swing resulted in no discernible differences in averaged vital signs compared to the supine position in NICU infants.

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IMPACT:

- We identified no significant differences in averaged oxygen saturation, heart rate, or respiratory rate among NICU infants placed in a semi-upright swing compared to the supine position.
- Desaturation events occurred at a higher frequency in low-birth-weight infants and those on room air when placed in the swing, although none required oxygen supplementation.
- The results from the current study support that it is probably safe to use semi-upright swings in the NICU environment, although additional studies are necessary for generalization to the unmonitored home environment.

BACKGROUND

Active sitting devices, such as semi-upright swings, and bouncers are increasingly used to soothe infants in both hospital and home environments.[1] Despite reports of significant innovation and consumer satisfaction, the impact of these devices on infant health remains unknown. Product recalls initiated by the United States Consumer Product Safety Commission were related to deaths or serious injury to infants placed in these devices.[2] While the exacting standards for structural integrity of these devices are widely described, they are principally directed at the prevention of unintended injury. Therefore, the extent of physiologic changes in infants seated in a swing or a bouncer, specifically contributing to the risk of sudden infant death syndrome and suffocation, remains unclear.

The American Academy of Pediatrics (AAP) cautions against sitting devices in general as sleeping environments and warns against its use in infants under the age of 4 months and those who are at risk of falling over, suffocation, or airway obstruction.[3] However, these recommendations have not mitigated the widespread use of car seats, strollers, swings, and slings, with one study reporting that an average infant spends almost 6 h a day in a sitting device.[4]

To address the knowledge gap related to the physiologic changes that accompany the use of an electronically activated swing, we sought to determine whether the placement of an infant in the swing results in discernible changes in vital signs. We hypothesized that the semi-upright position in the swing is associated with significantly lower average oxygen saturation compared to the supine position in the crib among infants in a neonatal intensive care unit (NICU). In addition, we explored the changes in other vital signs, including heart rate (HR), and respiratory rate (RR), and the documented apnea, bradycardic, and desaturation events.

METHODS

Study design

We conducted a within-subjects, prospective, observational study of infants, from October 2018 to October 2019, admitted to a level IV NICU at

[1]Division of Neonatology, Department of Pediatrics, University of Maryland School of Medicine, Baltimore, MD, USA. [2]Department of Pediatrics, University of Maryland School of Medicine, Baltimore, MD, USA. [3]Department of Otorhinolaryngology—Head and Neck Surgery, University of Maryland School of Medicine, Baltimore, MD, USA. [4]Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, USA. ✉email: dmetwally@som.umaryland.edu

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the University of Maryland Children's Hospital in Baltimore, MD. The study was approved by the institutional review board at the University of Maryland School of Medicine. Inclusion criteria included any inborn or outborn infants corrected to at least 34 weeks of gestation. The exclusion criteria included the need for invasive respiratory support at the time of the study, uncorrected congenital heart conditions, genetic or chromosomal disorders, hypoxic ischemic encephalopathy, and in general any unstable infant who does not meet internal guidelines for eligibility to be seated in a swing. Parental consent was obtained for each subject.

We used the MamaRoo® (4moms, Pittsburgh, PA), which moves up and down and sways from side to side when placed in a relatively constant recline between 30° and 45°, as a representative swing in the current study. Following placement of an infant in the swing, the tightness of the harness was checked to allow one finger-width distance between the harness and the infant. A preset motion setting was chosen to simulate a car ride.

From each infant enrolled in the study, data were collected 24 h apart from two positions—a semi-upright position in the swing and the supine position in the conventional crib, serving as his or her control. The order of placement in the crib or the swing was random to following standard of care guidelines for the eligibility of placement in the swing. The infants were matched by the time of the day for each position. For example, if the infant was placed in the swing by a caregiver from 1300 to 1500 h on a day, then the data from the supine position from the next day of 1300–1500 h was used for comparison. The standard of care for infants' feeds was every 3 h at 3, 6, 9, and 12 h. If the event was recorded during or after a feed, it was manually recorded by the nursing staff in the electronic medical record. None of the infants were placed in the swings during feeds.

Study variables included sex, gestational age at birth, birth weight, delivery type, comorbid conditions, respiratory support, gestational age, Apgar scores, and toxicology screens. Admission diagnosis and other significant events during NICU stay were also included.

Oxygen saturation (SpO_2) and HR were recorded prospectively using the Nellcor™ N-600x (Medtronic Inc., Firdley, MN) neonatal bedside monitoring system. RR was downloaded from the patient monitoring system (Solar 8000i, General Electric Corporation, Boston, MA). Each dataset comprised epochs of data averaged every 10 s that passed quality control and was downloaded at 48 h following enrollment. The cardiorespiratory events representing apnea, bradycardia, and desaturation were collected for each infant grouped by the recording position. Apnea was defined as an unexplained cessation of breathing for ≥20 s.[5] Bradycardia was defined as a HR <80 beats per minute and lasting at least 5 s.[6] A desaturation event was a pulse oximetry reading <90% for at least 10 s.[7] The electronic medical record was reviewed for nursing documentation of routine care that occurred every 3 h. Saturation target ranges for infants 33–44 weeks post menstrual age (PMA) was 90–97% with alarm limits 88% (low) and 98% (high). For infants >44 weeks PMA, target SpO_2 was >92%.

A sample size of 65 was calculated for the detection of small (Cohen $d = 0.2$) to medium (Cohen $d = 0.5$) effect size for the difference in average oxygen saturation between the two positions with a power of 0.8 and a type I error threshold of 0.05.[8] This would facilitate the detection of differences in mean oxygen saturation levels ranging from 2 to 5% between the groups.

Statistical analyses

Descriptive analysis comprised representation of counts and percentages for categorical variables and means and standard deviations for continuous variables.

We used mixed models for comparisons of outcome measures between groups based on observations of non-independence of data arising from its hierarchical or multilevel structure.[9] Such a model allows assessment of fixed effects such as experimental conditions (e.g., location of the infant in the swing or in the supine position) as well as random effects that include subject-level variability such as the physiological maturity of each infant and the variable durations of recordings.

In the current study, we used linear mixed effects models for comparisons of continuous variables average SpO_2, HR, and RR. For comparison of desaturation events, a categorical variable, we used a generalized linear mixed effects model. The exponentiated odds ratio from this generalized model was converted to the risk ratio, representing the ratio of the probability of a desaturation, a binary event, in the swing to its probability in the crib. In the overall study and the subgroups defined using respiratory support and history of low birth weight (LBW), we assessed the risk ratios following adjustment for the covariates. In the current study, the subject ID and duration of measurements were random factors and age, sex, and race/ethnicity were fixed effects. We assessed interaction effects based on whether they were on room air or received respiratory support or had a history of LBW. Finally, although the time in the swing was not experimentally controlled, we additionally explored the temporal trends for both oxygen saturation and HR as dependent variables with time as a fixed effect.

Statistical analyses were performed using R (version 3.6.1, https://cran.r-project.org). For mixed effects modeling, we used the lme4 package.[10] All mixed models were compared before and after adding the location variable using the Bayesian information criterion (BIC),[11] with a difference in BIC exceeding 10 strongly favoring the test model in comparison with the alternate.[12] A P value <0.05 was statistically significant.

Table 1. Demographics and type of respiratory support.

Male, *n* (%)	34 (52)
Ethnicity, *n* (%)	
Black	33 (50)
White	26 (40)
Hispanic	3 (5)
Other	3 (5)
Cesarean section, *n* (%)	43 (66)
APGAR (1 min)	6 [3,8]
APGAR (5 min)	8 [7,9]
Birth weight (g)	1915 ± 968
Low birth weight, *n* (%)	45 (70)
Gestational age at birth (weeks)	32.4 ± 5.1
Gestational age at study (weeks)	39.8 ± 3.4
Respiratory support at study, *n* (%)	
No respiratory support, *n* (%)	39 (60)
Low-flow nasal cannula, *n* (%)	13 (20)
High-flow nasal cannula, *n* (%)	6 (9)
Continuous positive airway pressure (CPAP), *n* (%)	6 (9)
Non-invasive positive pressure ventilation (NIPPV), *n* (%)	1 (2)
Type of feeding, *n* (%)	
Breast milk, *n* (%)	36 (55.4)
Formula, *n* (%)	24 (36.9)
Mixed breast milk/formula, *n* (%)	5 (7.7)

Categorical variables are summarized by number (%), mean ± standard deviation, or median [interquartile range].

RESULTS

Sixty-five infants were included in the study and their baseline characteristics are summarized in Table 1. The mean gestational age at birth was 32.4 ± 5.1 weeks and the mean adjusted gestational age at time of study was 39.8 ± 3.4 weeks (range: 34–41 weeks). Of the 26 infants on some form of non-invasive respiratory support, 13 (20%) were on low-flow nasal cannula.

Infants with chronic lung disease at 36 weeks corrected age ($n = 25$, one infant was <36 weeks GA) were on a combination of one or more diuretics, inhaled steroids, bronchodilators, and supplemental salts. Intraventricular hemorrhage was noted in 3 infants ($n = 2$ grade 1 and $n = 1$ grade 4). One infant was on sildenafil for pulmonary arterial hypertension. One infant had short bowel syndrome secondary to bowel resection after necrotizing enterocolitis and was on total parental nutrition. One infant was on propranolol for arrythmia. No infants were on caffeine during the time of the study.

A total of 125,112 recording epochs were obtained lasting 10 s each and comprised an equal number (62,556) of recordings from the two positions. This corresponded to an average of 160 min of recording in each position (range of 120 to 230 min). The mean SpO_2 was 95.68% (95% confidence interval [CI], 95.65–95.72%) in supine position compared to 95.55% (95% CI, 95.52–95.59%) in the swing. The mean HR was 151.74 beats per minute (95% CI, 151.60–151.89 beats per minute) and 150.93 beats per minute (95% CI, 150.78–151.08 beats per minute) in the supine position and the swing, respectively. The mean RR was 54.40 breaths per minute (95% CI, 53.28 to 55.52 breaths per minute) in supine compared to 54.58 breaths per minute (95% CI, 53.48 to 55.68 breaths per minute) in the swing. There were no significant differences between the two positions for the proportions of time spent with oximetry recordings below 95% (supine: 16.0%; swing: 16.7%), 90–94% (10.8% and 12.1%, respectively), 85–89% (2.5% and 2.7%, respectively), and below 85% (0.8% and 0.9%, respectively).

The comparisons of averaged vital signs between the swing and the supine positions are shown in Fig. 1, which demonstrate modest increases in oxygen saturation ($\beta \pm$ SE, 0.24 ± 0.03; $P <$ 0.001) and in RR (1.14 ± 1.34; $P = 0.40$) and a slight decrease in HR

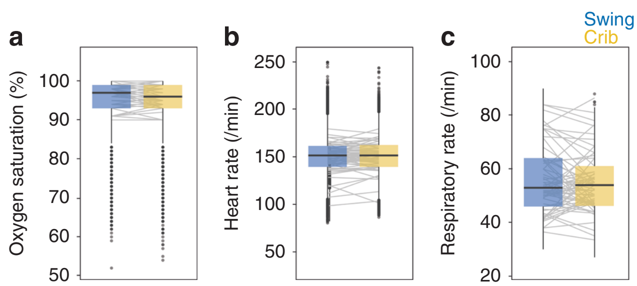

Fig. 1 Summary of changes in vital signs in infants placed in the swing compared to the crib. Boxplots represent the changes in oxygen saturation, heart rate and respiratory rate by the extent of the box showing the 25th–75th percentile of the distribution of data, the horizontal line representing the median and the vertical line representing the range with additional data points showing the outliers. In addition to between-group differences, the within-group differences are shown by patient-level changes by the connected lines between the two boxplots in each panel. Statistical comparisons are further shown in Table 2 and were significant for both oxygen saturation (**a**) and heart rate (**b**) although relatively small in magnitude. On the contrary, the differences were not significant for respiratory rate (**c**).

(-1.28 ± 0.10 bpm; $P < 0.001$) in the swing compared to the supine position. Table 2 summarizes these changes and provides the associated BIC values, which confirms the improved model fit with the addition of the position variable for average oxygen saturation and HR values but not for RR.

Additional effects related to respiratory support and LBW are shown by the BIC values of the models, including the interactions, are shown in Fig. 2 and Table 2. While infants placed in the swing were more likely to have slightly greater frequency of desaturation events (4461 [3.6% of total recordings] versus 4099 [3.3%]; relative risk [RR], 1.12; 95% CI, 1.05–1.18). However, this increased risk was identified only among infants on room air (RR, 1.24, 95% CI, 1.15–1.33) and those with history of LBW (RR, 1.55, 95% CI, 1.42–1.69).

The exploratory analysis of temporal trends (Fig. 3) in oxygen saturation and HR showed that infants placed in the swing experienced reduction in HR over time as shown in Fig. 3f, h, although the effect was small ($\Delta R^2 = 0.02$, $P < 0.001$). There were no other significant overall changes in trends or subgroup effects. There were no apneic events in infants in the swing or the crib. Five bradycardia events were documented (4 infants were LBW) in the swing that required stimulation. While none of the infants experienced apneic events, 3 infants experienced bradycardia and all 5 infants had desaturations below target. Out of these, three had spontaneous resolution of the bradycardia, one required tactile stimulation, and another required repositioning. No oxygen supplementation was required for any of the infants. No consistent predictors of these events were identified.

DISCUSSION

Electronic sitting devices are increasingly used as soothing aids for infants in both home and hospital environments.[1] However, given the association between infant deaths and the use of sitting devices in general, the AAP considers them unsafe sleeping environments.[13–16] Despite their widespread use, little is known regarding the impact of active swings on vital signs in infants. We utilized a comparison within subjects of infants in the NICU, in which each infant was placed in a crib and a swing in random order and determined the changes in vital signs and the prevalence of adverse events. The results from this study demonstrate placement of infants in swings did not result in discernible or clinically significant changes in vital signs. The average saturation for the cohort did not fall below the clinically significant target threshold of 90% for the study cohort. A recent study utilizing near infrared spectroscopy, showed no difference in

Table 2. Summary of main and interaction effects related to vital signs in infants placed in the swing compared to the crib.

Parameter/event	Main effect of position			Interaction effects			
				On respiratory support		LBW	
	Linear mixed effects regression						
	β (SE)	ΔBIC	P	ΔBIC	P	ΔBIC	P
Oxygen saturation	−0.24 (0.03)	80	<0.001	456	<0.001	170	<0.001
Heart rate	1.21 (0.01)	148	<0.001	175	<0.001	130	<0.001
Respiratory rate	−1.14 (1.34)	−5	0.41	5	0.34	0	0.98
	Generalized linear mixed effects regression						
Oxygen saturation <90%	−0.12 (0.51)	2	<0.001	7	<0.001	35	<0.001

The coefficients (β) along with the standard errors (SE) are listed for the linear mixed model that includes the position (crib versus swing), age, sex and race as fixed effects, and the number of recordings and patient ID as random effects. The outcome variables were oxygen saturation, heart rate, and respiratory rate. The change in model fit compared to a covariate only model was measured by the Bayesian information criteria (BIC) and the associated P value. A mixed effects regression was also used to model the likelihood of desaturation events, defined as a recording epoch with oxygen saturation below 90%. For all four outcome variables, we assessed the impact of interaction with the history of low birth weight and the presence of respiratory support.

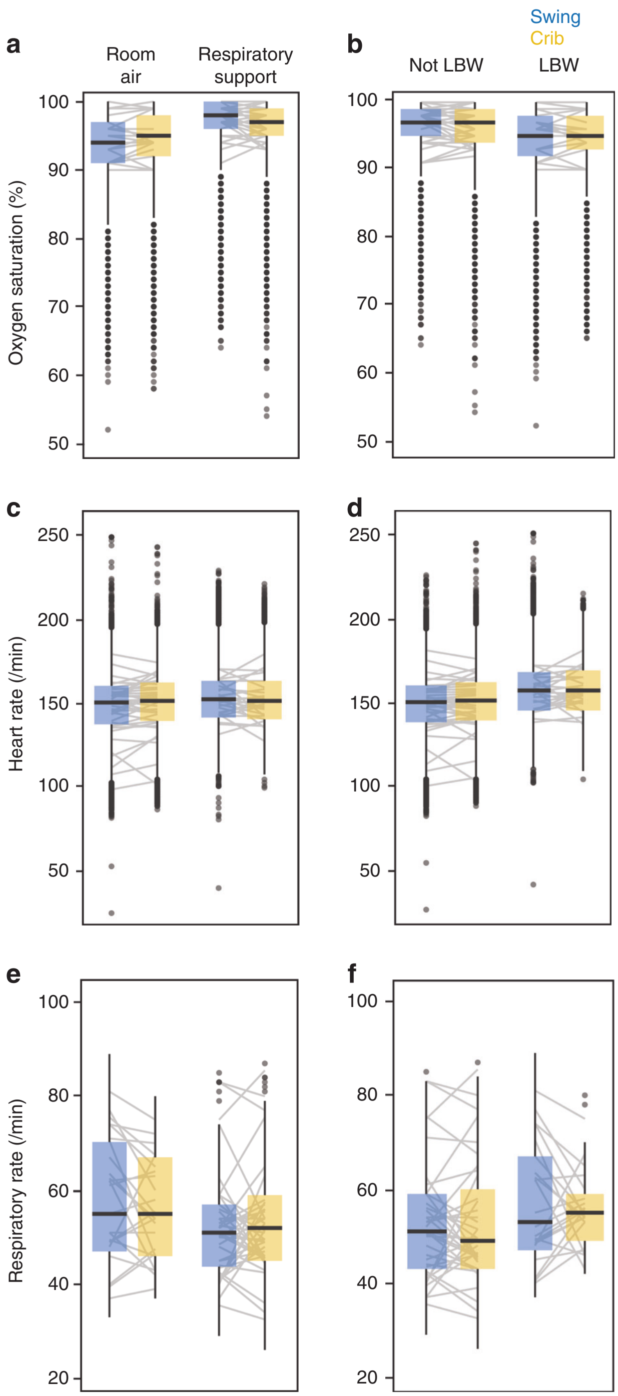

Fig. 2 Summary of subgroup effects related to the changes in vital signs in infants placed in the swing compared to the crib. Boxplots represent the changes in oxygen saturation (**a**, **b**), heart rate (**c**, **d**), and respiratory rate (**e**, **f**) by the extent of the box showing the 25th–75th percentile of the distribution of data, the horizontal line representing the median and the vertical line representing the range with additional data points showing the outliers. They are further stratified by whether infants were on room air or not (column 1) and whether infants had a history of low birth weight (LBW, column 2). Statistical comparisons of interaction effects related to respiratory support and history of LBW are further shown in Table 2 and were significant for both oxygen saturation and heart rate although small in magnitude. On the contrary, the interactions were not significant for respiratory rate. In addition to between-group differences, the within-group differences are shown by patient-level changes by the connected lines between the two boxplots in each panel.

cerebral regional oxygen saturation, which ranged from 68 to 90%, whether infants passed or failed the car seat test.[17] The subgroup effects, i.e., the increased risk of desaturation events in LBW infants and those on room air indicate the need for further studies in this subpopulation and caution until these effects are characterized further.

Most previous studies have focused on physiologic changes among infants placed in car seats.[17–22] For example, in term infants, Merchant et al.[18] demonstrated a decline in mean oxygen saturation from 97% in the supine position to 94% after 60 min in car safety seats. Furthermore, 8% had oxygen saturation below 90% for longer than 20 min. These findings were replicated in further car seat studies.[19,20] However, the current study did not demonstrate similar changes in oxygen saturation.

The observed differences noted compared to infants in the car seat may be attributable to the positioning of the pressure points and the changes in autonomic control. A car seat has straps on the chest with buckles near the neck and harness strap along with adjuster straps for both, a swing has two straps that buckle near the pelvic region. The direction and position of the straps, although directed towards transportation safety, may impact chest wall compliance and reduce tidal volume via pressure on the diaphragm in infants placed in the car seat.[21] Cumulatively, these aspects of the design of the car seat may impact oxygen saturation.

The average oxygen saturation was lowest among LBW infants placed in the swing although this modest difference compared to the supine position is likely of low clinical significance. The increase in desaturation events in swings was logged by the oximetry sensor as well as the serious events documented by the bedside nurse. The occurrence of events in infants with a history of LBW, potentially is linked to the immature central nervous system regulation of upper airway tone with an increased susceptibility to airway obstruction. In addition, putative mechanism may be neck flexion, elevated nasal resistance, and a highly compliant chest wall in the semi-upright position.[23] These findings also appear to be consistent with the findings from other studies in which a precipitous decline in oxygen saturation was observed over time among LBW and late preterm infants placed in the car seat.[22,24,25]

The swings in the current study did not show motion-associated benefits. Some, but not all, studies of rocking or water beds showed a reduction in the number of episodes of apnea and bradycardia.[26–28] The beneficial impact was related to the use of an oscillating bed while in a supine position; a key difference is the semi-upright positioning in the swing study. The investigators in these studies proposed that motion-evoked mechanical stimulation of the diaphragm or changes in autonomic discharge to airway dilator muscles may promote airflow.[28]

Importantly, infants on respiratory support were possibly protected against hypoxia as this group had significantly lower proportion of recording epochs representing desaturation events while in the swing compared to those on room air. These results are also consistent with previous study that demonstrated mitigation of respiratory events using supplemental oxygen in infants that failed the car seat tolerance screen.[29]

In the current study, the five bradycardia events were identified in five infants placed in the swing. Episodes of hypoxemia and bradycardia with or without apnea decreases blood flow in the anterior cerebral artery by 10–50% as HR falls below 100 bpm.[30] Moreover, mild bradycardia (60–80%) in preterm infants was associated with significant decrease in cerebral oxygenation.[31]

The current study has the following strengths. The use of the within subject observational design with placement in the two positions 24 h apart minimizes the residual effect of either position. Our data collection followed frequent sampling of blood oxygen saturation using 10-second epochs. The exploration of subgroups such as those with history of LBW and/or need for

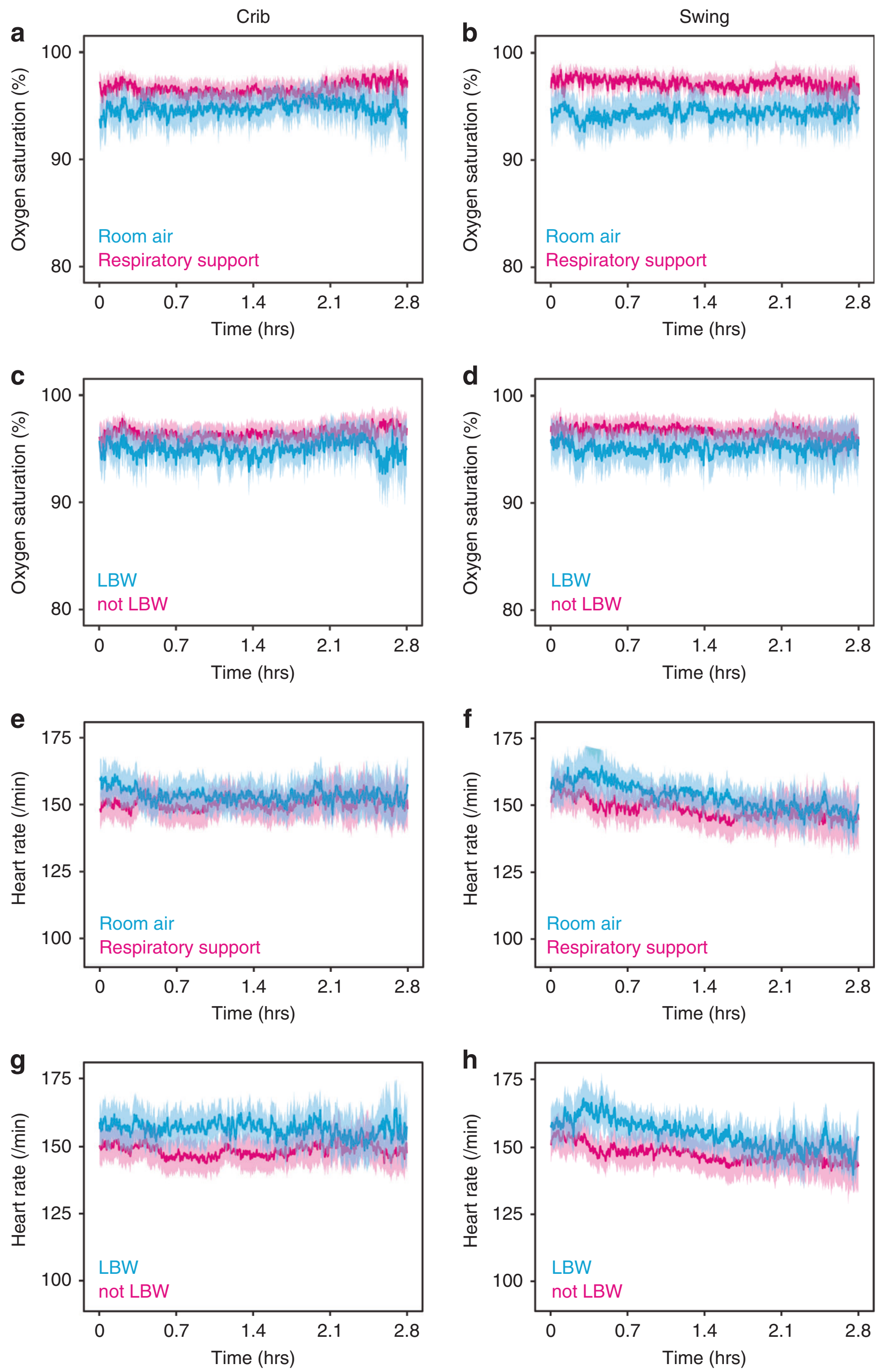

Fig. 3 Summary of temporal trends in oxygen saturation and heart rate in the crib and the swing. Infants were grouped by the need for respiratory support (**a**, **b**, **e**, **f**) and history of low birth weight (LBW, **c**, **d**, **g**, **h**). The trend lines are averaged over the subgroups as listed in the legend and accompanied by shading that represents the 95% confidence interval. The only trend lines that show decline over time are the heart rate in infants in the swing (**f**, **h**). Only the first 2.8 h (1000 recording epochs lasting 10 s each) are shown due to decreasing precision beyond this limit.

respiratory support provide opportunities to extend the investigation to these infants. The use of mixed models and high-frequency sampling of vital signs further increase the rigor of the study design.

The principal weakness of the study is related to the lack of polygraphic and video recordings to capture sleep staging, event monitoring and airflow measurements. The addition of these tests may have better illuminated the potential causal mechanisms of the desaturation events in addition to improved reliability in assessing cardiopulmonary variation. The significant heterogeneity of the study cohort is a relative weakness as the study findings may not be readily generalizable to individual subgroups due to the multiplicity of the statistical testing. It is also possible that the data in the nursing documentation may have contained errors. It is important to highlight that the infants in this study were closely monitored by bedside nurses in the NICU for proper positioning in the swing to prevent head flexion, which could lead to narrowing of the upper airway sliding downward, causing suffocation[13] or strap slippage and subsequent fall.[15]

The current results may be potentially translated to infants nearing transfer from the NICU. Respiratory support apart from low-flow nasal cannula is generally not provided at home. Therefore, results under these conditions cannot be generalizable in entirety to the safety of swing devices at the home environment. Future investigations that include additional centers, other levels of NICU care and possibly healthy infants at home may be necessary before the results and conclusions are widely generalizable.

CONCLUSION

Semi-upright swings are increasingly being used in the NICU as soothing aids to infants. In the current study, the placement of a monitored infant in a swing is not associated with discernable changes in vital signs supporting their relative safety in the NICU environment. While not a primary outcome in the study, a slightly higher rate of desaturation events and sporadic bradycardia in the swing especially among LBW infants warrant further investigation, although it was reassuring none of the infants required oxygen supplementation. A limitation of the current study is that the results were obtained from monitored infants in the NICU and therefore cannot be readily generalized to infants at home without additional studies in that population.

DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

S.K. conceptualized and designed the study, collected data, drafted the initial manuscript, and reviewed and revised the manuscript. A.I. performed and interpreted the data analyses and reviewed and revised the manuscript. D.E.-M. conceptualized and designed the study, coordinated, and supervised data collection and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the local Institutional Review Board. Parents of all subjects gave written consent to participate in the study.

ADDITIONAL INFORMATION

Correspondence and requests for materials should be addressed to Dina El-Metwally.

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