The Effects of Environmental Noise and Infant Position on Cerebral Oxygenation

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ABSTRACT

PURPOSE: To assess how different infant positions and peak sound levels affected cerebral oxygen saturation over time.

SUBJECTS: Twenty-four premature infants who were born less than 32 weeks' gestational age without congenital cardiac, neurologic, and gastrointestinal anomalies.

DESIGN: Repeated-measures design with the first observation between 2 and 48 hours of life; once again between 49 and 96 hours of life; on day of life 7; and every 7 days thereafter until discharge home, transfer to another hospital, or 40 weeks postmenstrual age, whichever came first.

METHODS: Continuous sound levels (decibels) were obtained and 2 infant positions were performed while measuring cerebral oxygen saturation during 40-minute observation periods.

MAIN OUTCOME MEASURES: Effect of peak sound and differences in infant position on cerebral oxygen saturation.

RESULTS: Peak sound levels 5 dB above the average ambient sound level did not significantly change cerebral oxygen saturation values. Differences in cerebral oxygenation were significantly less when infants were changed from a supine, head midline position to a right lateral, 15° head elevation compared with a left lateral, 0° elevation position.

CONCLUSIONS: Aspects of the current neonatal intensive care unit environment do not appear to affect cerebral oxygen saturation.

Key Words: cerebral oxygenation, NICU environment, positioning, premature infants, sound

Early experiences of infants with the environment establish how neurons in the maturing brain communicate with each other.[1] Therefore, reducing the negative impact of the environment is essential. Neonatal care has incorporated developmental protocols that include cycled light,[2] clustered care, and handling and positioning techniques to reduce the impact of the neonatal environment on the health of premature infants.[3] The more immature an infant at the time of neonatal intensive care unit (NICU) environment exposure, the more vulnerable the infant's brain to alterations of function and structure.[4] The neuronal pathways established from early experiences guide how the brain will experience future encounters with the environment.[4] Thus, premature infants' experience within the NICU environment may affect brain processing for the rest of an infant's life.

Noise and positioning of the infant are 2 factors in the NICU environment that could influence the structure and functioning of a premature infant's brain. One way in which noise and body position may influence the brain is through alterations in

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cerebral blood flow. Cerebral blood flow provides the brain with glucose and oxygen necessary for brain development[5] and for infants born less than 32 weeks' gestation, fluctuations in cerebral blood flow can result in cerebral damage.[6] Auditory stimulation from the NICU environment could disrupt the pathway of neurologic signals in the less-mature brain,[7] which could eventually alter the distribution of cerebral blood flow to the brain and potentially result in cerebral damage. Particular head and body positions such as a turned head or lying prone may reduce, or reduce and then increase, blood flow to the brain.[8-10]

One method to measure fluctuations in cerebral blood flow during position changes and high sound levels is cerebral oximetry. Cerebral oximetry measures cerebral oxygenation, the amount of the oxygen-saturated hemoglobin in the cerebral vasculature,[11] and it has been shown to correlate with cerebral blood flow.[12] Therefore, monitoring cerebral oxygenation may be a method for clinicians to detect cerebral blood flow fluctuations. An increased understanding about changes in cerebral oxygen saturation during position changes or loud sounds may permit the development of interventions to prevent severe fluctuations in cerebral blood flow that are hypothesized to result in cerebral damage.[6]

Average sound levels in the NICU have decreased over the last few decades, but peak sound levels continue to be a problem.[13-16] The current recommendation is that peak sound levels be no greater than 65 dB,[17] but levels often exceed 100 dB.[15,18,19] Intermittent changes in sound levels can also be used to identify noise, defined by peak sound levels exceeding 5 to 15 dB above ambient sound levels.[20] Sound levels exceeding 45 dB affect premature infants by disrupting sleep-wake states[14,15,21] and as sound levels increase, premature infants' metabolic demand for oxygen increases,[15] which, in turn, increases cardiac function.[14] As a result, peripheral oxygen saturation decreases, respiratory rate increases, especially in infants with respiratory compromise,[3] and the heart rate either increases or decreases as the infant tries to compensate from the exposure to the loud sound level.[14,18] Yet to date, the effects of peak sound levels on cerebral oxygen saturation during premature infants' hospital stays have not been examined.

Another environmental factor, premature infant position, may alter cerebral oxygen because body or head positions can crimp blood vessels, slowing, changing, or halting blood flow patterns.[8-10] Fluctuations in cerebral blood flow are hypothesized to cause brain damage in premature infants; however, the characterization of the fluctuations is not well understood. Whether damage occurs from fluctuations in cerebral blood from high to low flow or low to high flow, or from smaller fluctuations around a certain threshold, is unknown. Specific head or body positions believed to be benign may be responsible for fluctuations in cerebral blood flow that are responsible for brain damage, but further investigation is needed.

Most studies have examined the effect of infant position on cerebral blood flow rather than on cerebral oxygenation. Using Doppler ultrasound to view various vessels, cerebral blood flow was found to be lower in the prone position than in the supine position, and it increased with age even in the prone position.[22,23] However, other studies suggested that the prone position was the best position to alleviate apneic events in preterm infants by promoting cerebral blood flow.[24] In still other studies, a midline head position and tilting have been shown to promote cerebral blood flow. When preterm infants' heads were turned to the right or left, blood flow was lower than that in a midline head position.[25] These differences were not significant once the head was elevated 30°.[25] An elevated head, also known as tilting, can decrease cerebral blood flow[26] because of decreases in intracranial pressure as gravity pulls blood away from the head. Other studies challenge this conclusion, finding increased cerebral blood volume[27] and no differences in cerebral blood flow between a flat or tilted position.[28] These contradictory findings prohibit drawing any definitive conclusions about the best position to promote optimal cerebral blood flow and oxygenation.

Although most studies examined cerebral blood flow, a few studies have monitored cerebral oxygen saturation in different infant positions. Cerebral oxygen saturations were lower in the prone versus supine position; however, cerebral oxygen saturations decreased in both prone and supine positions over time in full-term infants.[29] However, 2 studies have found no difference in cerebral oxygen saturation during sequenced positions using a flat, tilted, or prone position.[30,31] The current literature on the effects of infant position on cerebral oxygen saturation is inconclusive.

Assumptions exist in practice and in the literature that a supine, head midline position is the best position to promote cerebral blood flow and reduce risk for cerebral damage.[32,33] However, contradictory findings in past studies prohibit drawing any definitive conclusions about the best position to promote optimal cerebral blood flow and oxygenation. In addition, once the threat of initial cerebral damage such as an intraventricular hemorrhage passes, whether position or peak sound levels continue to threaten cerebral blood flow or cause cerebral damage is unknown. Longitudinal examination of how peak sound levels and position effect cerebral oxygen saturation is needed to clarify these findings.

Clearly, noise and infant position are 2 aspects of the NICU environment that may negatively impact cerebral blood flow. Because brain development requires cerebral blood flow to nourish the brain, monitoring cerebral oxygen saturation may be one method to measure the effects of the NICU environment on cerebral blood flow. However, more must be known about the effects of infant position and NICU sound on cerebral oxygen saturation to identify potential interventions to ameliorate any untoward effects. Therefore, the purpose of this study was to assess how environmental noise and different infant positions affected cerebral oxygen saturation over time in premature infants born less than 32 weeks' gestational age.

In addition to position and peak sound levels, caffeine and cerebral oximeter probe location also affect cerebral oxygen saturation trajectories. In a recent study, caffeine administration, a methylxanthine drug prescribed to premature infants with apnea of prematurity,[34] was related to decreased cerebral oxygen saturation values in premature infants.[35] Decreased cerebral oxygen saturation has also been noted when measuring various regions of the brain based on different areas of cerebral oximeter probe placement. Cerebral oxygen saturation was lower with left frontal hemisphere monitoring compared to the right frontal hemisphere.[36] Therefore, location of the cerebral oximeter probe must be considered in study analyses if study procedures include a switch in probe location between the right and left frontal lobes.

This study was guided by the theory of probabilistic epigenesis, a developmental systems theory, which emphasizes the influences between the internal and external environments during developmental periods in premature infants.[37] The internal environment was measured by cerebral oxygen saturation and sound levels and infant position represented 2 factors of the external environment that premature infants are exposed to during hospitalization. Cerebral oxygenation was measured longitudinally as cerebral oxygen saturation is hypothesized to be a maturational process dependent on the age of the infant.

METHODS

Participants

The study enrolled a convenience sample of 24 premature infants at a level III NICU in southeast United States to longitudinally investigate the effects of sound and infant position on cerebral oxygen saturation measurements in premature infants. All infants born less than 32 weeks' gestational age were considered for inclusion in the study because this age group is at risk for intraventricular hemorrhage and other neurologic issues, which may be indicated by altered cerebral oxygenation during specific positions or peak sound levels.[6,38,39]

Infants with identified anomalies affecting the neurologic, gastrointestinal, or cardiovascular systems were excluded from the study to decrease confounding effects of abnormal anatomy that might affect cerebral oxygenation. Furthermore, infants born elsewhere and transferred to the research site were excluded because it was difficult to obtain parental consent within the first 48 hours of life. Also, unlike infants born in-house, infants transported from other institutions experience stressors related to neonatal transport, which may have confounded cerebral oxygen saturation results.[40,41]

Measures and Variables

Infant position and environmental sound were monitored continuously during each observation to assess the effects of the external environment on cerebral oxygen saturation (Table 1).

Cerebral Oxygen Saturation

Cerebral oxygen saturation, measured by a cerebral oximeter, is the amount of oxygen present in arteries and veins of the brain.[11] The FORE-SIGHT Cerebral Oximeter (CAS Medical Systems, Branford, CT) was used to noninvasively measure cerebral oxygen saturation during the entire 40-minute observation, which consisted of an oximeter probe attached to a monitor cable that was connected to a cerebral oximeter monitor. At one end of the oximeter probe, a light source penetrated the skull and cerebrum using fiber optics[42] to emit laser light.[43] At the other end of the oximeter probe, a light detector received the laser light sent from the light source. The amount of cerebral oxygen present within the arteries, veins, and capillaries of the brain was calculated using a modified Beer-Lambert law[44] ranging from 0% to 100% in whole numbers and displayed on the cerebral oximeter screen that was updated every 1 second. A laptop with software created exclusively for this study downloaded real-time cerebral oxygen saturation values from the FORE-SIGHT Cerebral Oximeter to a Microsoft Office Excel spreadsheet.

Peak Sound

The NoiseProDL Noise Dosimeter, made by Quest Technologies, was used to measure sound levels in 1-dB increments from 40 to 140 dB during the first 20 minutes of each 40-minute observation. The first 20 minutes was monitored only because all infants in the study were placed in the same body position, supine, head midline, unlike the last 20 minutes where they were randomized to different body positions. Average sound levels (Leq) were determined for each 1-minute period.[45] Using QuestSuite Professional II Software (Quest Technologies, Oconomowoc, WI), the noise dosimeter data were downloaded to a laptop computer at the completion of each observation. The first sound level 5 dB (Leq) greater than the average for the entire 20-minute observation was treated as a peak sound based on the intermittent peak sound-level criteria.[20] Peak sound levels were used to examine whether changes in sound level would elicit a physiologic response seen by measuring cerebral oxygen saturation. Cerebral oxygen saturation measurements 30 seconds before and 2 minutes after a qualified peak sound level were extracted as a data set from each observation for statistical analysis to assess whether a peak sound level changed cerebral oxygen saturation. A peak sound-level variable was coded as zero before the peak sound event and coded 1 in 30-second increments (total of four 30 seconds) after the peak sound event.

Infant Position

Each observation included 2 positions, each lasting 20 minutes. The first position was always a supine, head midline for every infant. The second position was randomly assigned to 1 of 5 possible positions (see Table 1). A 45°-angled foam pillow was used to verify 45° head angles in the 2 randomized, supine positions. The 5 positions were rotated in a different random order for each infant. These 5 positions were a subset of the 14 positions used by nurses to care for premature infants in the NICU. Five positions were chosen because 5 observations were estimated to be achievable during an average length of stay, 23 days, in the proposed infant population at the chosen research site. The supine, head midline during the first 20 minutes was coded as 1 and each randomized position was coded 2 to 6 in the order listed in Table 1.

Gestational Age

Gestational age was determined from either the first day of a woman's last menstrual period or an obstetric ultrasound to calculate expected date of confinement. If these dates differed by more than 2 weeks from the Ballard assessment of gestational age at birth,[46] the Ballard assessment was used to determine gestational age.

Postmenstrual Age

Postmenstrual age was used as the time variable in the positioning analysis. Postmenstrual age was calculated as gestational age at birth plus the number of weeks since birth in whole weeks.

Demographic Variables

Maternal and infant demographic variables were collected from electronic medical records for the purpose of describing the research sample. Maternal health characteristics such as age, medications used during pregnancy, and infant characteristics, including gender and birth weight at the time of infant enrollment, were collected. Cumulative data to describe infant events and care during an infant's hospital stay were collected from the medical record over the course of study enrollment.

Covariates

This study controlled for caffeine and probe location as covariates hypothesized to impact cerebral oxygen saturations.

Caffeine

Caffeine citrate is a methylxanthine drug prescribed to premature infants with apnea of prematurity[34] and has been shown to decrease cerebral oxygen saturation values in premature infants.[35] Caffeine was a time varying covariate in this study, as its use changed throughout an infant's hospitalization. At each observation, an infant given any route of caffeine administration as a therapeutic dose within the last 24 hours of the observation was considered to be a recipient of caffeine. Those infants who receive caffeine were coded as one and those who do not receive caffeine were coded as zero.

Probe Location

The cerebral oximeter probe was placed either right or left of center on the forehead above the brow. The chosen probe location was dependent on which side the forehead would potentially detect the most change in cerebral oxygen saturation in the second randomized position. For example, an infant turned from the supine, head midline position to a prone position with their head turned to the left would have had left-sided cerebral oxygen saturation monitoring. The left-side monitoring compared with the right side monitoring would be best at capturing the potential

TABLE 1. Observation Timeline

Timeframe	Cerebral Oxygenation	Infant Position	Sound
0-20 min[a]	X	Supine, head midline, 0° elevation	X
21-40 min[a]	X	Randomized to one of the following positions:	
		1. Right lateral with the head of bed elevated 15°	
		2. Prone with head to the left, 0° elevation	
		3. Left lateral with the head of bed at 0° elevation	
		4. Supine with head 45° to the right, 0° elevation	
		5. Supine with head 45° to the left, 15° elevation	

[a]2-48 hours of age, 49-96 hours of age, and day of life 7 and every 7 days until discharge or 40 weeks postmenstrual age.

for the vasculature in the neck to be disrupted because of the position. Probe location was dummy coded as a 0 for the left side and 1 for the right side.

PROCEDURES

Institutional review board approval and parental consent were obtained prior to the first observation. Cerebral oxygen saturation was measured longitudinally in 2 different infant positions between 2 and 48 hours of life; once between 49 and 96 hours of life; on day of life 7; and every 7 days thereafter until discharge home, transferred to another hospital, or 40 weeks postmenstrual age, whichever came first. Each observation lasted 40 minutes. Peak sound levels were measured only during the first 20 minutes of each observation since position could confound the potential effect of sound. All infants were placed in a supine, head midline position for peak sound-level analysis. Thus, analyzing the interaction between peak sound levels and position was not part of this study. Infants were positioned supine head midline with 0° elevation during the first 20 minutes and then for the last 20 minutes, randomized to 1 of 5 positions. Table 1 shows the position assignments for each 20-minute time period. Three observations in the first week of life identified the effect of sound and infant position on cerebral oxygen saturation as the infant transitioned to extrauterine life. Weekly observations were conducted at later ages because less dramatic maturational effects were expected after the first week of life. If an infant required surgery, the observation was postponed for 2 days to decrease the effects of anesthesia and postoperative recovery on study results. If the infant was unable to tolerate the study procedures for the scheduled day, the observation was postponed until the next day and the time for the next study observation was reset from this new day.

A cart was brought to the infant's bedside, which carried all of the instrumentation required for this study (cerebral oximeter, noise dosimeter, and laptop). The FORE-SIGHT Cerebral Oximeter was connected to the infant via a cerebral oximeter probe placed on the infant's left or right side of his or her forehead above the brow using an elastic headband to secure the probe during each observation. An elastic band was used to secure the probe rather than adhesive tape to avoid the possibility of skin breakdown. The FORE-SIGHT Cerebral Oximeter was connected to a laptop using USB extension cables, and the cerebral oxygenation levels were downloaded into a Microsoft Office Excel file. The noise dosimeter microphone was taped inside the isolette port closest to the infant's head for those infants in an isolette and for those infants not in an isolette, and the noise dosimeter microphone was placed within 6 inches of the infant's head.

Observations began 10 minutes after applying the cerebral oximeter probe to the infant as a prior study showed that patient manipulation might affect cerebral oxygen saturation for several minutes.[47] Observation of cerebral oxygen saturation occurred through 2 different positions, each lasting 20 minutes for a total of 40 minutes between feedings or scheduled nurse assessment times. Average sound levels were collected only during the first 20 minutes of each observation. At the end of each observation, sound data were downloaded via infrared transfer from the noise dosimeter to a laptop.

Data Analysis

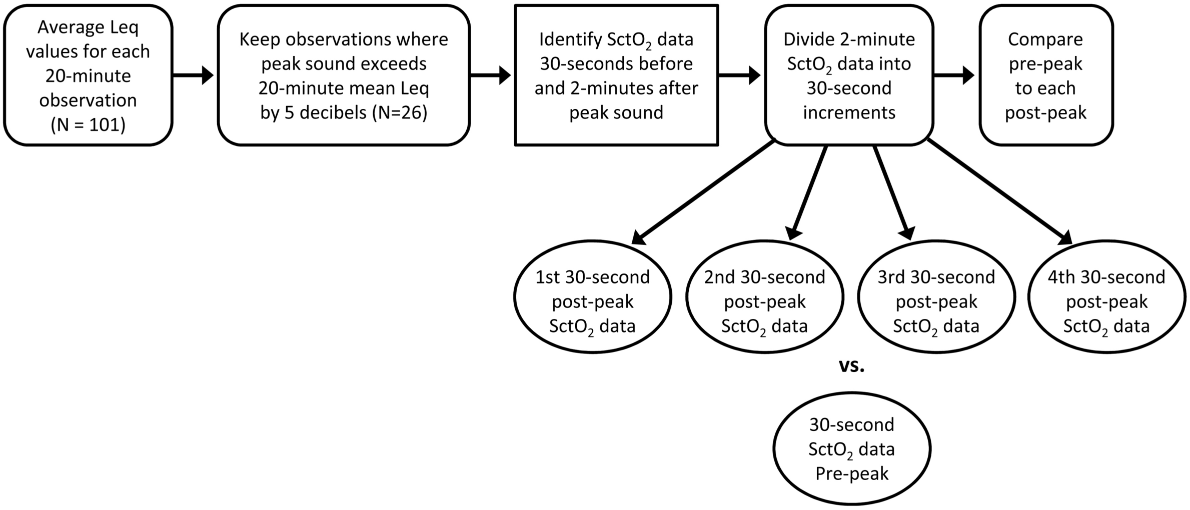
Peak Sound

General linear mixed models were used to examine the effects of peak sound levels on cerebral oxygen saturation in premature infants. Cerebral oxygen saturation during the 30 seconds before and 2 minutes after the first qualified peak sound level was extracted from each observation (Figure). Sound levels were averaged over the first 20 minutes of each observation, and a sound level greater than 5 dB above the average sound level was considered a peak sound level. One- and 2-second data points were averaged to 30-second mean cerebral oxygen saturation values. Then, the 30-second prepeak mean cerebral oxygen saturation value was compared with four 30-second mean cerebral oxygen saturation values postpeak sound level (2 minutes postpeak) to determine the effects of peak sound on cerebral oxygen saturation. The 30-second prepeak sound level was used as a reference compared to each of the four 30-second mean cerebral oxygen saturation values postpeak. Gestational age, probe location, and caffeine were the 3 covariates.

Infant Position

Mixed general linear models were also used to assess the effects of infant position on cerebral oxygen saturation. For each observation, cerebral oxygen saturation was measured in the supine, head midline position and then in 1 of the 5 randomly assigned positions to determine the effects of position change on cerebral oxygen saturation. Five comparisons resulted from contrasting the supine, head midline position with the 5 randomized positions. For statistical purposes, differences in mean cerebral oxygen saturation were calculated to keep both positions within the same observation paired together. For example, mean cerebral oxygen saturation for position 1 minus the mean cerebral oxygen saturation for position 2 within the same infant, same observation. Each differenced group was used as a reference totaling 5 mixed models. In order, each group contained differences in cerebral oxygen saturation between a supine, head midline and the following: (1) right lateral, elevated head of bed 15° (N = 16); (2) prone, head turned to the left (N = 18); (3) left lateral, 0° elevation

FIGURE.



Data management process for sound analysis. Study data were collected and managed using Research Electronic Data Capture[51] tools hosted at Duke University. REDCap is a secure, Web-based application designed to support data capture for research studies, providing: (1) an intuitive interface for validated data entry; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for importing data from external sources.

(N = 24); (4) supine, right head turn 45°, 0° elevation (N = 19); and (5) supine, left head turn 45°, 15° elevation (N = 24). Probe location and caffeine were the covariates along with quadratic and cubic effects of time and their interactions with the covariates.

RESULTS

Peak Sound

In the 26 observations meeting criteria for examining peak sound effects, mean cerebral oxygen saturation prepeak was 71.4% and the four 30-second postpeak average cerebral oxygen saturation values were 69.6%, 69.9%, 72.4%, and 72.8%, respectively. These cerebral oxygen saturation values may seem low in comparison to a better-known oxygen-monitoring tool, peripheral oxygenation. However, normative cerebral oxygen saturation values ranged from the high 70% in the first few weeks of life and slowly decreased to the mid-60s by 11 weeks of age.[48-50] Mean sound level at prepeak was 58.7 dB (ranging from 50 to 68.6 dB) and the four 30-second postpeak mean sound levels were 65.6, 65.1, 60.2, and 60.1 dB, respectively. Peak sound levels 5 dB above the average ambient sound level did not significantly change cerebral oxygen saturation values (Table 2). Gestational age and probe location were covariates and found to be nonsignificant, resulting in no differences between infants based on their gestational age or left or right side cerebral oximeter probe placement. Those infants who did not receive caffeine during a qualified observation had significantly higher cerebral oxygenation values compared with those infants who received a therapeutic dose of caffeine.

Infant Position

Differences in cerebral oxygen saturation were assessed between the supine, head midline position and 5 other randomized positions. A total of 101 observations were analyzed across 24 premature infants. Table 3 shows average cerebral oxygen saturation values in each of the 6 positions. In all 5 models, differences

TABLE 2. Mixed Model Results: Effect of Peak Sound on Cerebral Oxygenation

Variable	Parameter Estimate	SE	*P*
Intercept[a]	69.66	4.66	<.0001
1st 30-s postpeak	1.5	0.97	.13
2nd 30-s postpeak	1.16	0.97	.24
3rd 30-s postpeak	0.35	0.98	.72
4th 30-s postpeak	−0.03	0.98	.98
Caffeine[b]	6.34	1.69	<.001

[a]*Intercept equals expected value for all infants starting at 25 + 5 weeks.*

[b]*Caffeine = 0, coded 1 when receiving a therapeutic dose, 0 for all others.*

TABLE 3. Mean Cerebral Oxygen Saturation Values by Position

Position	Mean Cerebral Oxygenation, %	SD
1. Supine, head midline	72.9	9.6
2. Right lateral, elevated 15°	71.9	8.8
3. Prone, head to left, elevated 0°	69.3	8.9
4. Light lateral, elevated 0°	71.7	11.9
5. Supine, head turned 45° to right	76	8.5
6. Supine, head turned 45° left, elevated 15°	73.6	9.9

TABLE 4. Mixed-Model Results: Differences in Cerebral Oxygen Saturation Between Supine, Head Midline 0° Elevation and Right Lateral, 15° Head Elevation Compared to All Other Positions

Variable	Parameter Estimate	SE	P
Intercept[a]	8.12	3.84	<.05
PMA	−0.57	0.15	<.01
Position 3[b]	−1.43	1.48	.33
Position 4[b]	−2.9	1.36	.04
Position 5[b]	−0.87	1.44	.55
Position 6[b]	−1.08	1.36	.43

Abbreviaton: PMA, postmenstrual age begins at 25 +5 weeks.

[a]Intercept represents difference in cerebral oxygen saturation between position 1 (supine, head midline) and position 2 (right lateral, 15° head elevation).

[b]Difference in cerebral oxygen saturation between position 1 (supine, head midline) and identified position (position 3 = prone, head to left, position 4 = left lateral, position 5 = supine, head turned right 45°, and position 6 = supine, head turned left 45°, elevated 15°).

in cerebral oxygen saturation between a supine, head midline position and all other positions became smaller as postmenstrual age increased. Irrespective of changes with postmenstrual age, differences in cerebral oxygenation were significantly less when infants were changed from a supine, head midline position to a right lateral, 15° head elevation compared with a left lateral, 0° elevation position (Table 4). Caffeine, probe location, the quadratic and cubic effects of time, and the interactions with these 2 covariates were all found to be nonsignificant.

DISCUSSION

Peak sound levels and 5 different infant positions were not found to significantly affect cerebral oxygen saturation values in premature infants over time. In 2003, reducing environmental sound and maintaining a neutral head position were 2 of many methods suggested to reduce brain injury when caring for NICU infants.[33] If brain injury results from fluctuations in cerebral blood flow,[6] using cerebral oxygen saturation as a proxy for cerebral blood flow within varying positions and during peak sound levels could examine the validity of these recommendations.

This is the first study to analyze the effects of sound on cerebral oxygen saturation in premature infants. Previous research suggested that premature infants consume more oxygen when stressed from loud sounds in the NICU environment.[15] As a result, cerebral oxygen saturation levels were hypothesized to be significantly lower because the additional stimulation from the sound would increase oxygen metabolism. Findings from this study appeared to refute this hypothesis. Cerebral oxygenation values were similar when pre- and postpeak sound levels were compared. Peak sound levels were a minimum of 5 dB above the average ambient sound during each observation used in the analysis. Because a 5-dB level increase is algorithmic and not additive and because all observations exceeded 45 dB,[14,15,21] this small increase in sound has the potential to significantly change physiology in medically fragile infants.

In general, the research setting had low to moderate levels of ambient sound during sampling times with average decibels ranging from 50.8 to 68.6 and the highest peak sound at 77 dB compared with peak sound levels of greater than 100 dB in previous studies.[18] As NICUs continue to strive for quieter units,[13] only small elevations in environmental sound values are typical. Given the inevitable exposure to some changes in sound levels, these findings are reassuring in that peak sound levels of 5 dB above a quiet ambient sound level did not affect cerebral oxygenation. Therefore, NICUs making considerable efforts to reduce sound levels are most likely protecting infants' cerebral oxygen saturation levels. However, these findings do not provide guidance about how cerebral oxygen saturation values might be affected when peak sound levels are much higher or are longer in duration, which might be the case in some NICUs during admissions or medical emergencies.

The randomized positions also had little influence on cerebral oxygen saturation. Surprisingly, the movement required to change an infant from a supine, head midline to a prone position did not significantly change cerebral oxygen saturation. Moreover, when infants were changed from a supine, head midline position to any of the other 5 randomized second positions, differences between a neutral position and the second randomized position decreased with an increase in postmenstrual age. Developmental supportive interventions were routine practice at this research site and infants were slowly and gently turned from 1 position to the next to decrease the overall effects of the maneuver by the same researcher. The sampled population included primarily fragile and severely ill infants. The age-related changes also reflect improvement in infants' health status over time. The health improvements likely led infants to become less affected by daily care tasks such as positioning.

The differences in the change of cerebral oxygen saturation from a neutral position to a right lateral, elevated head were significantly lower versus changing to a left lateral, nonelevated position. The variation in cerebral oxygen saturation between these 2 lateral positions may reflect a difference in head elevation because the right lateral position included a head elevation of 15° and the left lateral position was horizontal at 0°. An elevated head could pull blood away from the head due to gravity,[26] which could potentially decrease the amount of blood to the brain, reducing the availability of oxygen. As a result, the right lateral, head elevated 15° would have lower cerebral oxygen saturation. However, this does not explain why cerebral oxygen saturation was not significantly different between the 2 supine, head-turned positions (supine, head turned 45° to the left, elevated 15° and supine, head turned right 45°, 0° elevation). Possibly, the manipulation involved with turning an infant to a lateral position in combination with the head elevation could be drastically different compared to the manipulation required to turn the head 45° and elevate the head.

The possibility that a turned head causes a crimp or occlusion in the vasculature and lowers cerebral oxygenation was not confirmed, as all tested positions that included a turned head were nonsignificant. The head and hips were kept in alignment when the infant was turned to a lateral position and infants' vasculature should not have been crimped or bent. Therefore, it is unclear why a midline head and body position would change cerebral oxygen saturation values while a turned head, potentially altering the pathway of blood flow, would not change cerebral oxygen saturation. To further explore these findings, cerebral oxygen saturation will need to be monitored while going from a supine, head midline position to a left and right lateral position and examining both an elevated and nonelevated head.

Infants receiving caffeine had lower cerebral oxygenation saturation levels. Caffeine is a commonly prescribed medication for premature infants experiencing apnea of prematurity. The drug's action increases oxygen consumption considerably, which would explain why cerebral oxygen saturation was significantly lower in those infants receiving caffeine. Although this effect seems to be expected, the threshold for which cerebral oxygen saturation values could decrease to because of caffeine before becoming dangerous is not known.

The relatively small number of positions examined and the inability to analyze a supine, head midline position limited this study. Out of the 14 infant positions that neonatal nurses frequently use in the NICU, only 5 were examined. Eight more positions (supine, head midline and elevated; supine, head turned right and elevated; supine, head turned left; right lateral; left lateral and head elevated; prone, head to the right; prone, head to the right and elevated; and prone, head to the left and elevated) including the supine, head midline position, while measuring cerebral oxygen saturation, need to be examined to draw conclusions about whether or not position affects cerebral oxygen saturation. Although a supine, head midline position was included in this study, it was used as a reference position because it is considered to be the neutral position. Also, it is unclear why the 2 lateral positions caused the most significant change in cerebral oxygen saturation even though several positions that did not keep the head and body aligned were also examined. Further examination of the remaining positions may help explain the unclear findings from this study.

The supine, head midline position was the reference position subtracted from the 5 other randomized positions to determine a difference score associated with each position change. A significant intercept at 8.12 in Table 4 represents the predicted difference in cerebral oxygen saturation between a supine, head midline and a right lateral, 15° head elevation position for the youngest infant in the study. This difference is important to note because the overall difference in cerebral oxygen saturation from the first day of life to 77 postnatal days slowly decreased by approximately 15% (78%-63%).[48] A decrease in cerebral oxygen saturation over 8% during a position change is approximately half of the amount that cerebral oxygen saturation decreased over several weeks of aging. This study only compared differences in cerebral oxygen saturation from what was considered a neutral position and 5 randomized positions and did not specifically examine the neutral position as part of the analysis. Thus, another study is necessary to include a supine, head midline position as a comparison position because the assumption that it is a neutral position may be incorrect.

At this time, reasonable variations in sound levels (5 dB) above ambient sound and infant position do not seem to significantly affect cerebral oxygen saturation. The level III NICU where these data were collected had low to moderate levels of ambient sound. Our findings support that striving to meet sound-level recommendations and using various infant positions have an effect on cerebral oxygenation that is acceptable clinical practice. Peak sound levels less than 65 dB and no more than 15 dB above ambient sound are recommended goals for NICUs.[17,20] Although we cannot say that developmental turning or positioning provides more supportive care for premature infants; our findings demonstrate that infants cared for with these interventions did not have significant changes in cerebral oxygen saturation values. More research is needed in this area to better understand these findings and make further recommendations for practice in the NICU.

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