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Original article

Transmission of biological maternal sounds does not interfere with routine NICU care: assessment of dose variability in very low birth weight infants

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Abstract

Maternal auditory stimulation is playing an increasing role in neonatal critical care. The goal of this study was to determine the dose variability in the administration of Biological Maternal Sounds (BMS) in Very Low Birth Weight (VLBW) infants as part of routine clinical care in the Neonatal Intensive Care Unit (NICU). The BMS intervention aimed to provide infants with individualized and biologically appropriate auditory stimuli, featuring acoustic stimuli from their own mothers.

Sixteen preterm infants, born between 26-32 weeks gestational age (GA) and < 1,500 g, took part in this study. The study was conducted in a 46-bed, level-III NICU with four multi-patient pods. Mother's voice and heartbeat sounds were recorded individually for each infant. Nurses were instructed to administer BMS 4x per 24-hour period by pressing play on an MP3 player connected to micro-speakers installed in the infant's bed.

BMS was initiated for each infant on approximately the sixth day of life (DOL) (mean = 5.78 ± 2) and continued until NICU discharge (mean length of stay = 46.62 ± 27.28). On average, infants received 80% of the target BMS dose. There were no significant differences in BMS administration between nursing shift (day vs. night; p = 0.35), bed type (crib vs. isolette; p = .41), and respiratory support (on vs. off oxygen; p = .93). There was a slight increase in the number of times BMS was initiated on days without exams versus days with exams; however, this difference was not statistically significant (p = 0.07).

This study demonstrated the successful incorporation of maternal sounds into routine daily care in VLBW infants as early as DOL six until NICU discharge. The effectiveness of BMS needs to be further evaluated in a randomized controlled trial.

Keywords

Maternal, sounds, very low birth weight, neonatal care, preterm, NICU.

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Introduction

Advances in neonatal medicine have resulted in a significant reduction in infant mortality [1-3]; however, a significant decrease in long-term morbidities is yet to be achieved. Improving the NICU environment is an important step toward improving neonatal outcomes [4]. In fact, the chaotic nature of the NICU environment may be particularly detrimental for neurologic and sensory development [5]. This is especially evident when considering the premature infant's abrupt transition from the biologically appropriate and acoustically protective womb environment to the maternally-deprived and noisy NICU environment [6-9]. Biological sounds, such as the mother's voice and heartbeat, are the predominant source of auditory stimuli *in utero* [10, 11]. These sounds are important because they are likely the first sounds the fetus hears, thereby establishing the neural connectivity for the auditory system and wiring the fetus for language processing soon after birth [12, 13]. This natural course of sensory development is negatively altered during NICU hospitalization secondary to prolonged exposure to high-frequency noise coming from fans, ventilators, telephones, pagers, doors, loud conversations, and intermittent alarms [14-17]. Therefore, NICU noise should not only be reduced but also replaced with sounds that promote maternal-infant bonding and mimic the womb environment.

Maternal sounds are considered soothing for preterm infants and are thought to facilitate mother-infant attachment [13, 18]. Additionally, providing premature infants with low-frequency biological maternal sounds mimics the womb environment and is hypothesized to promote auditory brain development [19]. Many previous studies have incorporated soothing music, lullabies, maternal voice, and even live music within the NICU environment [20-25] (for review see [26]). These studies provided premature infants with various forms of auditory stimulation at different time points during the infant's NICU stay and observed the infant's behavioral and physiologic responses. While ample evidence regarding the effects of these sounds on neonates is still accumulating, little attention has been paid to the feasibility of a user-friendly audio system that would allow high quality simulation of biological maternal sounds for consistent playback in the infant's crib/isolette for the *entire duration* of an infant's NICU stay.

The purpose of this study was to assess the dose variability in administrating Biological Maternal Sounds (BMS) into the NICU without interfering with medical equipment or routine clinical care. This study focused on the following questions: Is it possible to implement BMS in the NICU within the first seven days of life? Is it feasible for BMS to be provided to VLBW infants 4x per 24-hour period throughout their NICU hospitalization? Is the BMS dosage affected by the nursing shift (day vs. night), the infant's bed type (isolette vs. crib), the infant's respiratory support (on/off oxygen), daily medical exams (exams vs. no exams), and number of days receiving BMS?

Methods

Participants

Sixteen VLBW infants (10 females, 6 males) born between 26-32 weeks gestational age (GA) took part in this study. All infants were admitted to a 46-bed, level-III NICU with four multi-patient pods. Infants had an average birth weight of 1,182 g (SD ± 206.15), birth GA of 30 weeks (SD ± 2.08), and an average NICU length of stay (LOS) of 46.62 days (SD ± 27.28). No infants withdrew from the study; however, six infants transferred to neighboring community hospitals to reduce the commute burden on parents. Infants' illness severity was assessed using the Score for Neonatal Acute Physiology-Perinatal Extension (SNAPEE-II); mean score 8.31 (SD ± 15.17). The SNAPPE-II is a measurement of illness severity and mortality risk developed to predict in-hospital mortality based on nine different physiologic criteria measured within the first 12 hours of life [27]. Infants with chromosomal or congenital anomalies, major congenital infections, history of maternal smoking, alcoholism, and use of illicit drugs were excluded from the study. A

description of infant characteristics is given in Table 1. This study received approval from the institutional review board of our hospital.

BMS Recording and Implementation

Mother's voice and heartbeat sounds were recorded for each infant in our specialized recording studio at our hospital. Voice recordings were done via a large-diaphragm condenser microphone (KSM44, Shure, USA) that captured a wide range of maternal vocalizations, such as speaking, reading, and singing. Heartbeat recordings were done via a digital stethoscope (ds32a, Thinklabs Digital Stethoscopes, USA). Next, sound recordings were attenuated using a low-pass filter with a cutoff of 400 Hertz to allow the highest fidelity of biological sound reproduction. Loud peaks of maternal vocalization were attenuated to achieve Lmax of < 65 dBA. The recorded soundtrack was then uploaded onto an MP3 player (Philips Electronics, SA2RGA04KS, Netherlands) for playback inside the infant's isolette/crib. Nurses received no formal BMS training; however, nurses were asked to watch an instructional video and during the initial months of subject enrollment, the NICU nurses were informed of the study's rationale and objectives by the principle investigator and the study team. Nurses were asked to implement BMS 4x per 24-hour period whenever caring for a study subject. The BMS was initiated by pressing the 'play' button on an MP3 player located behind the infant's isolette/crib (**Fig. 1A**). Nurses documented the exact time that they played BMS on bedside study sheets located on a clipboard next to the infant's bed.

Study staff conducted daily NICU check-ins to ensure that the audio systems were functioning properly and to consult with the bedside nurses regarding any questions or concerns pertaining to the study. Overall, implementation of BMS into the NICU was made possible by a team consisting of the infant's attending physician, the principle investigator, the study staff, the infant's parents, and the bedside nurse. Creating a user-friendly system that is easy to operate was crucial for successful implementation of the BMS intervention by the bedside nurse.

Patient Safety

The audio system used in this study has been previously validated in a safety study from our lab [28] (**Fig. 1A**). This particular system has been shown to: (a) have no electrical interference with medical equipment, such as cardiac monitors and ventilators; (b) withstand the high temperature (~36˚C) and humidity (~75%) levels often present inside the isolette; (c) be robust against frequent cleaning with disinfectant as per the infection control guidelines; and (d) deliver maternal sounds at a safe, fixed decibel level (< 65 dBA). An additional safety test was completed on the audio set-up using a Dale 600 Safety Analyzer to ensure electrical isolation (**Fig. 1B**).

A.

B.

Device	Ground Resistance (milliohms)	Leakage Current (microamps)	Safety Status
MP3 Player to Speakers	N/A*	0	pass
Speakers	N/A*	0	pass
Giraffe ® Incubator	0.15	80	pass
Power Transformer	N/A*	0	pass

*Isolated two wire system, no ground.

Figure 1.

A. The audio system used in this study consisted of two micro-speakers connected to an MP3 player located on the railing system behind the infant's bed (shown here inside a crib for illustration only).

B. This audio setup has been validated for electrical isolation to ensure patient safety and no interference with NICU medical equipment.

Data Collection

Study sheets at the bedside were used to document BMS dose administration. The number of times per 24-hour period that each infant was exposed to BMS was recorded separately for the day/night nursing shift. Day shifts were defined as 7:00 AM to 7:00 PM, while night shifts were defined as 7:00 PM to 7:00 AM. The first day of the study and day of discharge were excluded from data analysis because infants were not physically in the NICU for a full day in order to receive the full dose of BMS. In addition, online medical records were reviewed to determine bed type, respiratory support, days of daily medical exams/procedures, and LOS. Medical exams and procedures included: intubation and insertion of arterial or central venous lines, imaging studies, surgical procedures, electroencephalography, 2-month vaccination, and eye, hearing, and urine exams.

Data Analysis

Two-sample T-tests were applied to assess the feasibility of implementing BMS between the different nursing shifts (day/night), bed types (isolette/crib), respiratory support (on/off) – with 'on' defined as SIMV/CPAP/high/low flow nasal cannula and 'off' defined as room air, and medical exams (exams/no-exams). A linear regression analysis was completed to examine the daily BMS dose percent compared to the days on BMS.

Results

On average, BMS was initiated for each infant before DOL six (5.78 ± 2) and continued until NICU discharge (see **Fig. 2A**). Data taken from all subjects throughout their entire NICU stay showed that, on average, nurses administered BMS 3.23 out of 4x per 24-hour period. In addition, the infant's days on BMS did not affect the percent daily dose (R^2 = 0.063), suggesting that BMS administration was mostly consistent irrespective of the number of days the infant was receiving BMS (**Fig. 2B**). A two sample t-test revealed no significant differences in BMS implementation between day shift vs. night shift (p = 0.35) (**Fig. 3A**), crib vs. isolette (p = .41) (**Fig. 3B**), and on vs. off oxygen support (p = .93). There was a slight increase in the number of times BMS was administered on days without exams versus days with exams (**Fig. 3D**); however, this difference was not statistically significant (p = 0.07).

Discussion

The goal of this study was to determine the feasibility and dose variability of a new NICU intervention aimed at improving the auditory environment for VLBW infants, by consistently exposing them to their mother's voice and heartbeat sounds throughout the entire duration of their NICU stay. In the absence of a "gold standard" dose for this intervention, nurses

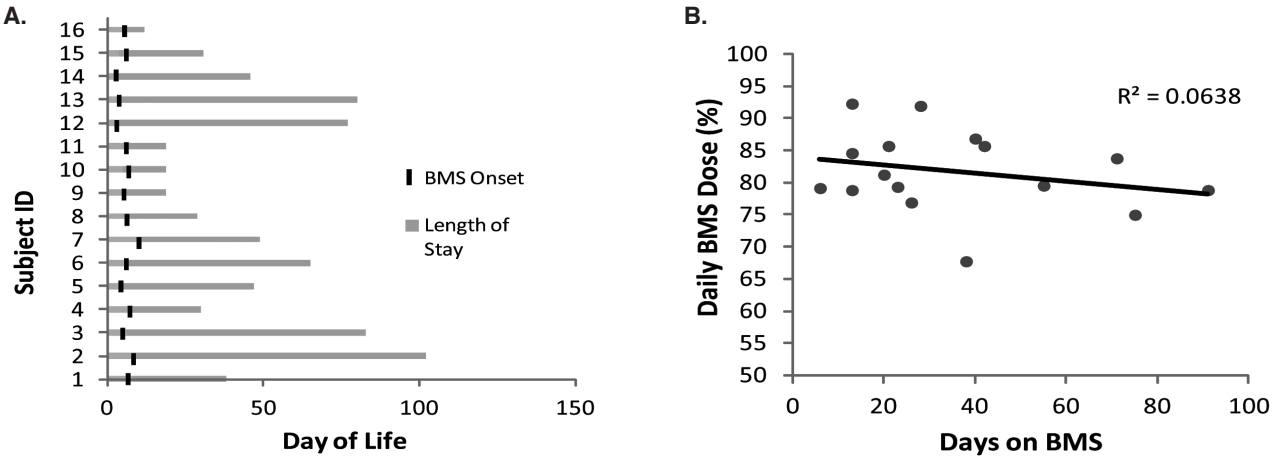

Figure 2.

A.The DOL BMS was first administered (black) is shown individually for each infant over the course of his/her NICU stay (gray), demonstrating the successful implementation of BMS soon after birth.

B. Linear regression shows that BMS daily dose remained consisted throughout the NICU stay (~ 80%), irrespective of the number of days an infant was receiving BMS (R^2 = 0.063).

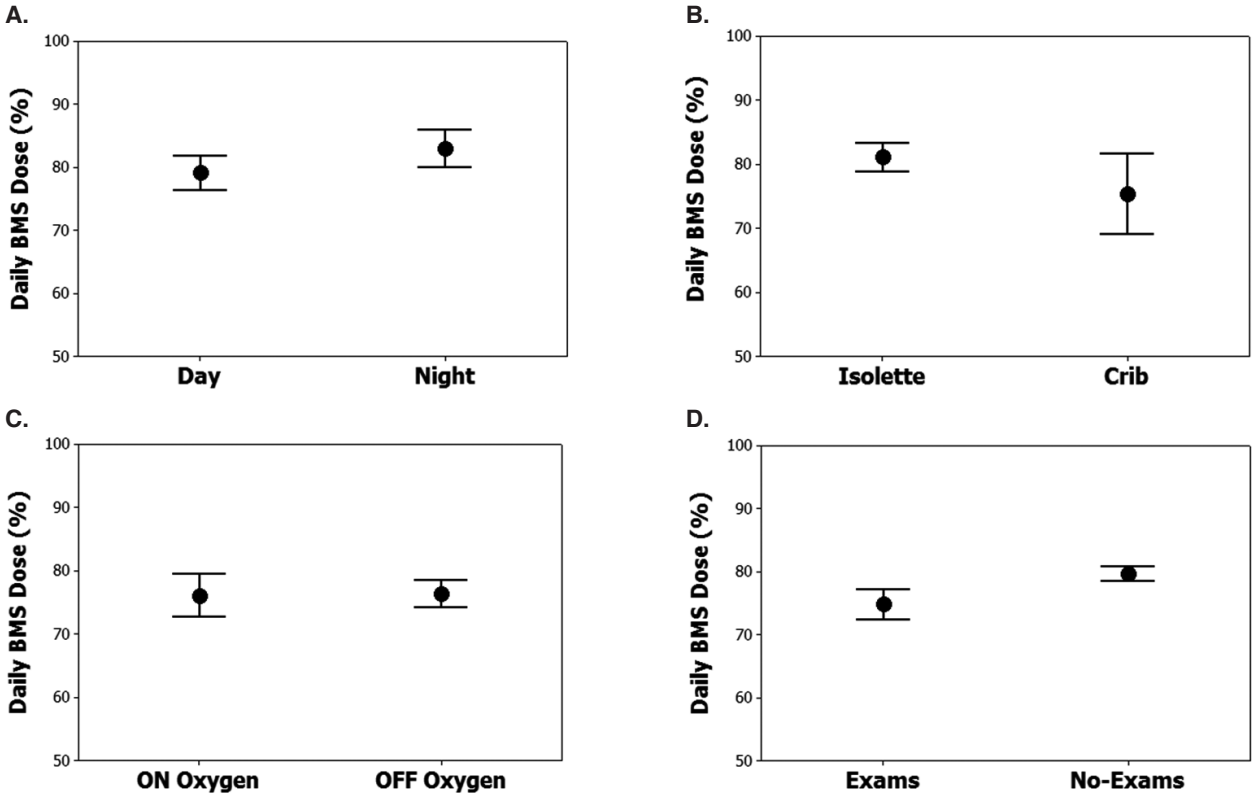

Figure 3. Dose variability analysis of all subjects through their entire NICU stay reveals that, on average, infants received 80% of the target BMS dose (i.e., nurses administered BMS 3.23 out of 4x per 24-hour period). Our results indicate that this dose variability was not affected by **A.** Nursing shift (day vs. night; p = 0.35); **B.** Infant's bed type (crib vs. isolette; p = .41); **C.** Respiratory support (on vs. off oxygen; p = .93); and **D.** daily medical exams (exams vs. no-exams; p = 0.07). Error bars represent standard error of the mean.

were instructed to administer BMS 4x per 24-hour period as the infant's daily schedule permitted. Although there was some variability in BMS dose-percentage, our data shows that, on average, infants successfully received 80% of the prescribed daily dose of BMS. These results demonstrate robust implementation of BMS in a large NICU setting and for high-risk VLBW infants.

The BMS was designed to modify the overwhelming NICU environment in an effort to minimize the stress experienced by the infant and to increase maternal-infant bonding, consistent with the approach of developmental care [29]. To achieve the prescribed dose of 100%, both the day- and night- nurses were asked to look at the infant's bedside study sheet and coordinate BMS so that it was provided twice per shift, making the total 4x per 24-hour period. Interestingly, although our daily interaction with the day nurses was significantly higher, we found no difference in BMS dose given between the day- and night-nursing shifts. These results are very encouraging because they demonstrate strong communication among the 161 rotating nurses in our 46-bed, level-III NICU, especially as it related to our study protocol.

It is important to identify developmentally appropriate interventions that can be implemented soon after birth to alleviate the abrupt transition from the womb to the NICU environment. One of the highlighted features of the BMS intervention is that it can be administered within only a few days post-partum. In the present study we found that, on average, BMS began in the infant's isolette at approximately DOL six. We aimed to have BMS initiated as soon as possible in an effort to continue the womb-like stimulation during a critical period of auditory development. Prenatal consent of bed-rest mothers at risk for preterm delivery may be considered for implementation of BMS immediately after birth. Continuous and appropriate sound stimuli are indispensable for the preterm infant, especially when born between 25-32 weeks gestation – a critical period for hearing development. During this period, major auditory

brain pathways, particularly to/from the cochlea, are being fined tuned for acoustic sensitivity and optimal hearing [10, 30, 31]. Auditory deprivation during this critical period may therefore impair the development of the auditory system.

The number of days the infant was receiving BMS did not alter the daily BMS dose percentage. Infants consistently received an average of 80% of the prescribed BMS over the course of their NICU stay. Although this trend decreased slightly over time, this could have been due to the fact that parents often visit more when their infants are older, more stable, and can be held and fed more regularly by their caregivers. It is important to note that the BMS was not intended to be a substitute for parental visits, and mothers were encouraged to provide their infants with skin-to-skin kangaroo care knowing that BMS will only be given at times when they cannot physically be in the NICU. Measuring the effects of BMS on the frequency of parent visits was beyond the scope of this study, but would be important to examine in the future.

It is interesting that infants in an isolette received similar levels of BMS compared to infants in a crib. This trend was also evident when examining the daily BMS dose of infants on versus off oxygen. These findings exemplify that BMS can still be incorporated into routine care even in the case of extremely vulnerable infants who are on respiratory support. The fact that BMS percent dose was not significantly different on days with medical exams versus without exams can be taken as further evidence for the feasibility of this intervention.

We have devoted a significant amount of time to better understand the instances when the target dose of BMS was not achieved in our NICU. Additional data based on nursing feedback confirms that when BMS was administered less than the prescribed dose it was often due to a number of reasons. For example, although signs were posted at the infant's bedside, some nurses reported being unaware that the infant was enrolled in the study. To address this, a short educational movie about the BMS intervention and protocol was made and distributed to all NICU nurses.

Having bedside nurses administer BMS added to their daily care routine for the infant. Nurses first examined the bedside study sheet to see when the BMS had last been administered, then pressed play on the MP3 player and then recorded the exact time that the BMS began playing. Difficulty adapting to BMS administration was likely the source of some of the dose variability seen across BMS administration. Because the nurses were instructed to administer BMS only when parents were not physically in the NICU, it was important that the nurse was aware of when the parents were planning on visiting. If parents visited at different times each day, this likely made the administration of BMS less consistent. We therefore encouraged parents to coordinate their visits with the nurse to ensure full dose administration. Finally, we found that our daily check-ins helped to remind the nurses about BMS administration as well as alleviated any technical issues related to the audio setup.

The optimal daily dose of BMS for NICU infants is still unclear. We know that if the infant was still in the womb, he/she would have continuous exposure to maternal sounds throughout the entire pregnancy, rather than only 4x per 24-hour period. However, the conservative approach taken by most neonatologists (including our research group), has been focused on avoiding overstimulation, mainly because evidence in this area is still unfolding. Thus, considering the high-risk population of VLBW infants enrolled in our study, BMS administration has been limited to only 3 hours per day (4x 45min). Using an automated audio system that would play the biological maternal sounds at pre-set times throughout the day may, ultimately, be less demanding on the nursing staff. However, this automated approach has been avoided as it ignores the infant's state and behavioral cues [29, 32]. In fact, Graven (2011) warns against the use of routine recordings in the NICU with high-risk infants [33]. Therefore, we purposefully considered the bedside nurses to be a good judge of when to play maternal sounds because: (1) they are fully in charge of the infant's daily schedule and can therefore ensure that the maternal sounds do not conflict with parent visitation times; and (2) in the absence of the parents, they are best the person to assess the infant's behavioral cues within the context of his/her typical responses and guide the maternal sounds accordingly. Often, the nurses played the BMS recording post-oral feed or during nasogastric feed when the infant was swaddled in his/her isolette/crib.

Lastly, we believe that an automated event marker, which records the exact time that BMS begins playing rather than manual recording by the nurses, would be much more reliable and accurate in logging the time of day BMS

is administered, and we intend to implement this type of automated timestamp with the next generation of our audio setup.

Conclusion

The results of this study demonstrate that, in spite of the widely variable NICU environment, providing VLBW infants with auditory stimulation of their mothers' voice and heartbeat is highly feasible and well supported by both parents and medical staff in our NICU. Previous studies have provided preterm infants with acoustic stimuli in the NICU [34-38]; however, this study is the first to incorporate maternal sounds into routine care on a daily basis throughout the *entire* course of the infant's NICU stay in a cohort of VLBW infants. Although the efficacy and optimal dose of the BMS intervention are not yet clear; the high feasibility and acceptability of this approach demonstrated in the current study is a crucial preliminary step toward testing the its effectiveness in a larger, randomized controlled trial. Future protocols that aim to implement such therapies in a routine fashion should consider the steps and recommendations presented below.

1. Have a designated member of the NICU research team routinely check-in with the bedside nurse to address any questions and/or concerns pertaining to the audio setup and BMS administration.
2. Encourage mothers of study subjects to inquire about whether or not BMS had been administered when they call the NICU to check on their infant(s).
3. Tape signs to the isolette/crib to remind nurses of the daily target dose of BMS.
4. Increase communication between nurses. This can be done by using the bedside study sheets or notes within the infant's chart denoting that the infant is enrolled in the study and when BMS was administered during previous shifts.
5. Coordinate BMS administration with parental visitation.
6. Use friendly technology that can be easily incorporated into the infant's isolette/crib and minimizes the time required from the bedside nurse for administration.
7. Perform safety checks on all equipment to ensure that there is no electrical leakage (according to hospital standards) and that none of the equipment is interfering with the infant's bedside monitor.
8. Have a designated study staff carrying a pager so nurses can page the staff 24/7 if there are any unexpected problems or technical difficulties regarding the BMS administration.

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Declaration of interest

No conflicts of interest exist.

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