Weight Gain Velocity in Very Low-Birth-Weight Infants: Effects of Exposure to Biological Maternal Sounds

Emily Zimmerman, PhD[1] Kristin Keunen, MD[1] Melanie Norton[1] Amir Lahav, ScD, PhD[1,2]

[1] Department of Newborn Medicine, Brigham and Women's Hospital, Boston, Massachusetts
[2] Department of Newborn Medicine, Mass General Hospital for Children, Harvard Medical School, Boston, Massachusetts

Address for correspondence and reprint requests Amir Lahav, ScD, PhD, Brigham and Women's Hospital, Newborn Medicine, 75 Francis St, CWN 418, Boston, MA 02115 (e-mail: amir_lahav@hms.harvard.edu).

Am J Perinatol

Abstract

Objective To examine the effects of biological maternal sounds (BMS) on weight gain velocity in very low-birth-weight (VLBW) infants ($\leq$ 1,500 g).

Study Design An exploratory study with a matched-control design. A prospective cohort of VLBW infants exposed to attenuated recordings of BMS during their neonatal intensive care unit hospitalization were compared with retrospective controls matched 1:1 for sex, birth weight, gestational age, scores for neonatal acute physiology and perinatal extension (SNAPPE - II) scores ($n = 32$).

Results A linear mixed model controlling for gestational age, chronic lung disease, and days to regain birth weight revealed that infants receiving BMS significantly improved their weight gain velocity compared matched controls ($p < 0.001$) during the neonatal period. No differences were found on days spent nothing by mouth ($p = 0.18$), days until full enteral feeds ($p = 0.51$), total fluid intake ($p = 0.93$), or caloric intake ($p = 0.73$).

Conclusion Exposure to BMS may improve weight gain velocity in VLBW infants. Further research is needed to evaluate the effectiveness of this noninvasive intervention during the neonatal period.

Keywords
- weight gain velocity
- auditory
- neonatal
- very low birth weight

Very low-birth-weight (VLBW) infants ($\leq$ 1,500 g) are at a heightened risk for developing growth restriction due to inadequate nutrition in the first weeks of life.[1–8] Despite advances in neonatal care, inadequate growth of VLBW infants remains very challenging. These challenges may arise from metabolic and gastrointestinal immaturity as well as from a compromised immune system and other medical complications.[9–11] If left untreated, growth deficiencies in the neonatal period have detrimental effects, such as growth failure and psychomotor deficits, that can persist throughout early childhood and into adulthood.[12–15]

Growth status and velocity are important health outcomes for VLBW infants.[16] The first 28 days of life, collectively considered the neonatal period, are especially important for growth and development because they represent the time that infants are most susceptible to illness and/or injury.[17,18] Therefore, regaining sufficient weight soon after birth is essential for establishing a consistent growth trajectory for the remainder of the infant's neonatal intensive care unit (NICU) stay. In fact, the American Academy of Pediatrics (AAP) committee on nutrition has recognized the importance of early, adequate nutrition for preterm infants and recommends that weight gain during NICU hospitalization should attempt to replicate the intrauterine growth velocity (15 g/kg/d) of a fetus at an equivalent gestational age (GA).[19] However, VLBW infants are often unable to attain such

received
August 29, 2012
accepted after revision
November 16, 2012

DOI http://dx.doi.org/10.1055/s-0033-1333669.
ISSN 0735-1631.

intrauterine-like growth velocities due to physiological immaturity and the presence of comorbidities.

Aside from having a VLBW, the maternally deprived conditions inside the incubator do not provide the preterm infant with an optimal environment to mature and develop. One way of optimizing the NICU incubator may be to attempt to restore the maternal aspects of the intrauterine environment by providing the infant with his or her mother's voice and heartbeat sounds that were otherwise present in the womb. Previous studies have yielded important information regarding the potent effect of soothing sounds on a wide range of short-term outcomes, including improved oxygen saturation,[20] cardiorespiratory stability,[21] and behavioral states[22–24] as well as improved energy expenditure,[25] caloric intake,[26] weight gain,[23,27] feeding tolerance,[28] and feeding length.[29,30] However, the previous research limits our ability to attain solid conclusions regarding the effects of soothing sounds on neonatal growth for two main reasons. First, with the exception of one study,[26] most studies have focused on healthy preterm infants who are $>$ 30 weeks' postmenstrual age,[25,29,30] rather than on VLBW infants in the first few weeks of life. Second, in most studies, infants were only briefly exposed to soothing sounds, usually for 2 to 3 days,[23,25,26] leaving the prolonged effects of auditory sounds on growth velocity outcomes largely unstudied. The present study aimed to fill this scientific void by (1) examining a high-risk population of VLBW infants born $<$ 33 weeks' GA; (2) focusing on the first 28 days of life; and (3) using attenuated recordings of the infant's mother's voice and heartbeat designed to mimic the womb environment. Thus, the main purpose of this study was to provide VLBW infants with biological maternal sounds (BMS) and measure the effects on weight gain velocity during the neonatal period. It was hypothesized that infants exposed to BMS during their NICU stay would have a faster weight gain velocity compared to retrospective matched controls.

Study Design

Participants

A total of 32 VLBW infants took part in this study. All subjects were admitted to the Brigham and Women's Hospital (BWH) NICU in Boston, Massachusetts. A prospective cohort of VLBW infants exposed to BMS during their NICU hospitalization were compared with a cohort of retrospective controls matched 1:1 for sex, birth weight (BW), GA, scores for neonatal acute physiology and perinatal extension (SNAPPE - II). The SNAPPE-II is a measurement of illness severity and mortality risk developed to predict in-hospital mortality based on nine different physiological criteria scored within the first 12 hours of life.[31] When there were two possible matches for an infant, the infant with the closest SNAPPE-II score, sex, GA, and BW was used as the match.

Inclusion criteria included the following: GA $\geq$ 25 and $\leq$ 33 weeks, as assessed by mother's dates and/or with the Ballard GA assessment; BW $\geq$ 700 g and $\leq$ 1,500 g. The age limits were chosen based on the knowledge that the human fetus begins to perceive and react to auditory information starting at approximately the 25th week of life[32,33] Exclusion criteria included the following: major chromosomal or congenital anomalies, major congenital infections, $\geq$ grade II intraventricular hemorrhage, necrotizing enterocolitis, and surgeries within the first 28 days of life.

The BMS group included 16 preterm infants (5 males, 11 females), with a mean birth GA of 28.8 weeks (standard deviation [SD] $\pm$ 2.2), mean BW of 1,089 g (SD $\pm$ 260), and SNAPPE-II score of 16.31 (SD $\pm$ 17.81). The retrospective

Table 1 Clinical Characteristics of Study Population

Parameters	BMS	Matched control	*p* value[a]
Neonatal data			
Males, *n* (%)	5 (31)	5 (31)	1.00
Birth GA (wk)	28.8 $\pm$ 2.2	28.9 $\pm$ 2.3	0.75
Birth weight (g)	1,089 $\pm$ 260	1,101 $\pm$ 231	0.45
SNAPPE-II score	16.31 $\pm$ 17.81	14.50 $\pm$ 16.46	0.24
Antenatal corticosteroids, *n* (%)	12 (75)	15 (94)	0.38
Days to regain birth weight	8.00 $\pm$ 4.13	7.31 $\pm$ 3.88	0.63
Morbidities			
Sepsis, *n* (%)	2 (13)	2 (13)	1.00
PDA, *n* (%)	8 (50)	5 (31)	0.38
RDS, *n* (%)	15 (94)	14 (88)	0.77
CLD, *n* (%)	10 (63)	8 (50)	0.56
IVH (grade II), *n* (%)	2 (13)	3 (19)	0.78

Abbreviations: BMS, biological maternal sounds; CLD, chronic lung disease; GA, gestational age; IVH, intraventricular hemorrhage; PDA, patent ductus arteriosus; RDS, respiratory distress syndrome; scores for neonatal acute physiology and perinatal SNAPPE-II.
Note: Morbidities are based on the first 28 days of life. Unless otherwise specified numbers are given as mean ($\pm$ standard deviation).
[a]*p* value is a result of a paired *t* test or Mann-Whitney for comparisons between groups.

matched controls included 16 preterm infants (5 males, 11 females), with a mean birth GA of 28.9 weeks (SD ± 2.3), mean BW of 1,101 g (SD ± 231), and SNAPPE-II score of 14.50 (SD ± 16.46). The mean GA, BW, and SNAPPE-II scores between the groups were not significantly different (see ►**Table 1**). Further analysis of matching accuracy for each matched pair separately indicates an average difference of 56 g for BW, 3 days for birth GA, and 3.5 points for SNAPPE-II scores. In addition, there were no statistically significant differences between the groups on common neonatal morbidities including sepsis, respiratory distress syndrome, chronic lung disease (CLD), and intraventricular hemorrhage (see ►**Table 1**).

Biological Maternal Sounds Group

BMS Recording

BMS recording was performed in a specialized recording studio at BWH. Voice recordings were acquired using a large-diaphragm condenser microphone (KSM44, Shure, Niles, IL) that captured a wide range of maternal vocalizations, such as speaking, reading, and singing. Heartbeat recordings were acquired with a digital stethoscope (ds32a, Thinklabs Digital Stethoscopes, Centennial, CO). Next, sound recordings were attenuated using a low-pass filter with a cutoff of 400 Hz to allow the highest fidelity of biological sound reproduction. The recorded soundtrack was then mixed with soothing sounds and uploaded onto an MP3 player (Philips Electronics, SA2RGA04KS, Amsterdam, The Netherlands) for playback inside the infant's isolette/crib 4 × per 24-hour period for 45 minutes.

Sound Safety

The audio system used in this study has been previously validated in a safety and feasibility study from our laboratory.[34] This particular system has been shown to: (1) have no electrical interference with medical equipment, such as cardiac monitors and ventilators; (2) withstand the high temperature (about 36°C) and humidity (approximately 75%) levels often present inside the isolette; (3) be robust against frequent cleaning with disinfectant as per the infection control guidelines; and (4) deliver maternal sounds at a safe, fixed decibel level. Loud peaks of maternal vocalization (< 65 decibal A-weighted (dBA)) were attenuated to achieve a safe level of sound delivery equivalent to normal human conversation.

Implementation of BMS in the NICU

Implementation of BMS into routine NICU practices was made possible by an effective collaboration between researchers and NICU medical staff, especially the nurses. Nurses were instructed to provide BMS 4 × per 24-hour period by pressing the "play" button on the MP3 player located behind the infant's isolette/crib. Implementation of BMS was documented daily by the bedside nurse.

Control Group

Infants in the control group received standard NICU care without implementation of BMS. This retrospective cohort of infants included neonates who were admitted to the BWH NICU within 3 years from the study onset. No changes in NICU construction, medical equipment, or nutritional protocols were made during this time.

Data Collection

Patient data were collected from medical records and nursing flow sheets. Data included BW, GA, sex, birth head circumference, administration of antenatal corticosteroids, and SNAPPE-II scores. A 28-day growth trajectory was used to examine the average daily weight gain (g) across the two groups during the neonatal period. To examine the weight gain velocity two common methods described in the literature were computed.

Calculating Growth Velocity

Weight gain velocity (g/kg/d) was determined by taking the infant's daily weight gain (g) divided by the previous day's weight (kg) for the first 28 days.

The exponential model (EM) is based on the premise that growth in biological systems is often nonlinear and occurs at a fraction of the previous weight. The EM accurately estimates postnatal growth velocity in VLBW infants throughout the NICU stay.[35–39] The equation used to calculate EM is: estimated $GV = [1{,}000 \times \mathrm{Ln}\,(Wn/W1)]/(Dn - D1)$, where GV = growth velocity, W = weight in grams, D = day, 1 = beginning of time interval, and n = end of time interval in days.

Additional outcome measures included the days to regain BW, duration of no feeding by mouth, days until full enteral feeds (140 mL/kg/d), caloric intake, and total fluid intake (mL/kg/d).

Statistical Analysis

The nutritional outcomes are presented in ►**Table 2**. A paired t test was used to examine the 28-day growth trajectory between the two groups. A linear mixed model (SPSS version 20) was used to examine the effect of the dependent variable (weight gain velocity) between the two groups (BMS versus matched control). Covariates included in the model were chosen a priori on the basis of their clinical relevance to impact growth during the neonatal period and included: birth GA, CLD, and the days to regain BW.[40,41] These covariates were entered into the model to account for differences in these factors thereby further increasing the power to detect significant effects.

Results

The 28-day growth trajectory reveals that, on average, infants exposed to BMS gained significantly more weight (1,220 ± 159 g) compared with matched controls (1,204 ± 137 g; $t = 3.35$, $p = 0.002$; see ►**Fig. 1**). Significant effects were also evident in growth velocity. A paired t test revealed a significant difference between infants exposed to BMS versus matched controls ($t = 2.21$, $p = 0.043$) with an average growth velocity of 13.13 g/kg/d (SD ± 3.17) and 10.96 g/kg/d (SD ± 2.54), respectively (►**Table 2**). Statistical significance remained strong after entering the growth velocity data into a linear mixed model (fixed effects) using birth GA, CLD,

Table 2 Nutritional Outcomes

Outcomes	BMS (n=16)	Matched-Control (n=16)	p-value
	Linear Mixed Model Estimated Means[a]		
Weight Gain Velocity is (g/kg/day)	13.45 (±7.37)	10.65 (±7.37)	**p < .001**
	Paired t-test Means		
Weight Gain Velocity (g/kg/day)	13.13 (±3.17)	10.97 (±2.54)	**p = .025**
28-day Growth Trajectory (g)	1,220 (±159)	1,204 (±137)	**p = .002**
Duration NPO (days)	2.56 (±2.70)	4.13 (±4.35)	**p = .18**
Full enteral feeds (140 ml/kg/day)	14.43 (±7.50)	15.25 (±9.09)	**p = .51**
Total Fluid Intake (ml/kg/day)	138.14 (±3.55)	138.38 (±10.41)	p = .93
Caloric Intake (kcal/kg/day)	100.75 (±14.32)	99.24 (±15.25)	**p = .73**

Abbreviation: BMS, biological maternal sounds; NPO, no oral feeding.
Note: Numbers are given as mean (± standard deviation).
[a]Estimated means have been entered into a linear mixed model to account for the following covariates: gestational age, chroniclung disease, days to regain birth weight.

and the days to regain BW as covariates ($t = 4.26$, $p < 0.001$) with an average growth velocity of for the BMS group of 13.45 g/kg/d (SD ± 7.37) and 10.65 g/kg/d (SD ± 7.37) for the control group (►**Table 2**).

A paired *t* test estimating postnatal growth velocity based on the EM (see Methods) revealed that the BMS infants (12.54 ± 3.22 g/kg/d) had a faster growth velocity compared with control infants (10.37 ± 2.72 g/kg/d; $t = 2.20$, $p = 0.044$). Overall, it is clear that BMS positively influences weight gain in the first 28 days of life.

There were no significant group differences on days to regain BW ($p = 0.63$), duration of no feeding by mouth ($p = 0.18$), days until full enteral feeds ($p = 0.51$), total fluid intake ($p = 0.93$), or caloric intake ($p = 0.73$; see ►**Table 2**).

Discussion

This study examined the effects of BMS on weight gain velocity in VLBW infants during the first 28 days of life. The results suggest that daily exposure to mother's voice and heartbeat sounds while in the incubator can result in a significantly faster weight gain velocity compared with routine exposure to NICU sounds. These effects remained strong after controlling for possible covariates, including GA, CLD, and days to regain BW. Infants receiving BMS gained an average of 13.13 g/kg/d—that is 2.16 g/kg/d more than the control infants (10.97 g/kg/d), and closer to the AAP recommendation of 15 g/kg/d. Although the weight gain increase may seem small on a day-to-day basis, over time it leads to meaningful differences. For instance, at day of life 28 infants in the BMS group weighed on average 1,532 g and infants in the matched-control group weighed on average 1,470 g. Although these amounts are not substantial for a full-term infant, considering the small size and the initial starting point of these VLBW infants, any additional weight gain is significant.

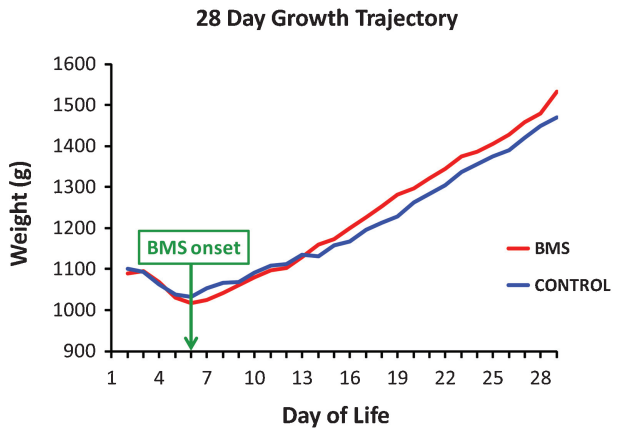

Fig. 1 The 28-day growth trajectory for the BMS group (red) compared to the control group (blue). Green vertical arrow indicates the average day of life when infants in the BMS group were first exposed to maternal sounds. An improvement in weight gain was evident at approximately day of life 13 when the BMS infants surpassed the controls. Abbreviation: BMS, biological maternal sounds.

Nutritional Outcomes

Interestingly, our data show that the primary difference between the groups was in weight gain velocity ($p < 0.001$; linear mixed model). However, despite emerging trends, no significant group differences were found for the other related nutritional outcomes, such as days without oral feeding, days to full enteral feed, total fluid intake, and days to regain BW (see ►**Table 2**). For example, the BMS infants reached full enteral feeds slightly sooner (14.43 days) compared to the control infants (15.25 days). Further research is needed to confirm whether BMS reduces time to full enteral feeding. Improvements in environment have been shown to reduce the days to reach full enteral feeds. Erickson and colleagues found that the time to reach full enteral feeds was reduced in infants in a private suite room compared with infants in an open-bay NICU.[42] Therefore, it is possible that the BMS group had a maternally enhanced NICU environment that fostered growth and reduced the time to reach full enteral feeds.

Several Possible Mechanisms for Increase in Growth Velocity

The lack of significant differences between the groups on days NPO, days to full enteral feed, and total fluid intake leave us to

assume that the BMS infants might have managed to preserve more energy, which in turn contributed to their improved weight gain. Although we did not measure this directly, we can only speculate that the soothing effects of BMS led to an overall reduction in stress; this led to improved sleep-wake cycles and behavioral states, which all together helped the infant to preserve more energy, thereby improving weight gain. Several possible mechanisms may be considered.

The inability of the premature infant to adapt accordingly from the soothing womb environment to the overwhelming NICU environment can result in an immense amount of stress that can impinge on growth and development.[43–46] Previous research has shown that the accumulation of background noise in the NICU may result in detrimental health effects.[47–51] Controlling the environment may allow for energy conservation and may, in turn, result in appropriate growth and development.[44] It is possible that the BMS replaced the noxious NICU noise with meaningful maternal stimulation resulting in an improved environment, thereby reducing the infant's stress level. However, in the absence of more solid physiological evidence for stress levels (e.g., cortisol), this hypothesis remains a rather speculative explanation.

Another possible explanation for the increase in weight gain observed by infants in the BMS group might be due to improved behavioral states. Previous studies have provided live music to premature infants in the NICU and found improved behavioral scores in the 30-minute interval after the music had been played.[22] Another study found a trend toward more mature sleep-wake cycles in subjects who were exposed to music compared with controls, suggesting that there might be a small effect of music on quiet sleep in newborns.[52] Thus, it is possible that infants receiving BMS were in active states longer and acquired more quiet sleep, which in turn helped them to preserve more energy and increase their daily weight gain. A subsequent study using a larger randomized controlled trial needs to be completed to further examine this hypothesis in more detail.

Weight Gain and Neurodevelopment

Growth status and velocity are important markers of health and well-being in VLBW infants. The benefit of early weight gain can extend beyond the neonatal period as postnatal growth in premature infants is a strong predictor of concurrent morbidities and neurodevelopmental outcomes.[2,3,53–55] Ehrenkranz and colleagues found that as the rate of weight gain and head circumference increased, the incidence of cerebral palsy, mental developmental index, psychomotor developmental index scores < 70, abnormal neurological examination, and neurodevelopmental impairment fell.[41] Therefore therapies, like BMS, that can noninvasively improve weight gain may possibly correlate with improved long-term neurodevelopmental outcomes in VLBW infants.

Study Limitations

This was an exploratory study and the generalization of the results may therefore be limited. The relatively small sample size was due to the investigators' goal of ensuring clinically relevant outcomes prior to pursuing a larger, randomized controlled trial. In addition, the small sample size was a result of our selective recruitment of a homogeneous cohort of VLBW infants, ruling out those who did not have morbidities that could potentially account for changes in weight gain velocity other than BMS.[56] However, these inclusion criteria significantly limited our sample size as it was difficult to find VLBW infants who did not have such comorbidities. The small sample size tested is a possible limitation to this study.

An additional potential limitation of the present study is our inability to determine the effects of BMS beyond the neonatal period. For example, it would have been interesting and clinically relevant to examine whether daily exposure to mother's voice and heartbeat can influence the infants' weight at NICU discharge. This, however, was not feasible for this specific study cohort because many of the infants were transferred to another NICU in a community hospital closer to home, leaving us with no data on their weight gain at term-equivalent age.

Conclusion

Exposure to biological maternal sounds during NICU hospitalization may improve weight gain velocity in VLBW infants in the first 28 days of life. These promising results require further studies with a larger sample size to confirm the findings and to elucidate the underlying mechanisms.

Acknowledgments

We thank Simon Manning for his comments and clinical advice on the manuscript. We also thank Sagori Mukhopadhyay for clinical advice, Yvonne Sheldon, Erin McMahon and Nicole Witham for assisting with data collection, and Steven Ringer, Robert Insoft, and the nursing team for facilitating the study in the NICU. This study was supported by the Gerber Foundation, Hailey's Hope Foundation, Peter and Elizabeth C. Tower Foundation, LifeSpan HealthCare, Little Giraffe Foundation, Jackson L. Graves, and Philips Healthcare.

References

1 Clark RH, Thomas P, Peabody J. Extrauterine growth restriction remains a serious problem in prematurely born neonates. Pediatrics 2003;111(5 Pt 1):986–990
2 Dusick AM, Poindexter BB, Ehrenkranz RA, Lemons JA. Growth failure in the preterm infant: can we catch up? Semin Perinatol 2003;27:302–310
3 Ehrenkranz RA, Younes N, Lemons JA, et al. Longitudinal growth of hospitalized very low birth weight infants. Pediatrics 1999;104(2 Pt 1):280–289
4 Ehrenkranz RA. Growth outcomes of very low-birth weight infants in the newborn intensive care unit. Clin Perinatol 2000;27:325–345
5 Lemons JA, Bauer CR, Oh W, et al; NICHD Neonatal Research Network. Very low birth weight outcomes of the National Institute of Child health and human development neonatal research network, January 1995 through December 1996. Pediatrics 2001;107:E1

6 Poindexter BB, Langer JC, Dusick AM, Ehrenkranz RA; National Institute of Child Health and Human Development Neonatal Research Network. Early provision of parenteral amino acids in extremely low birth weight infants: relation to growth and neurodevelopmental outcome. J Pediatr 2006;148:300–305
7 Marks KA, Reichman B, Lusky A, Zmora E; Israel Neonatal Network. Fetal growth and postnatal growth failure in very-low-birthweight infants. Acta Paediatr 2006;95:236–242
8 Embleton NE, Pang N, Cooke RJ. Postnatal malnutrition and growth retardation: an inevitable consequence of current recommendations in preterm infants? Pediatrics 2001;107:270–273
9 Georgieff MK. Nutrition. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 1999:363–394
10 Wright K, Dawson JP, Fallis D, Vogt E, Lorch V. New postnatal growth grids for very low birth weight infants. Pediatrics 1993;91:922–926
11 Olsen IE, Richardson DK, Schmid CH, Ausman LM, Dwyer JT. Intersite differences in weight growth velocity of extremely premature infants. Pediatrics 2002;110:1125–1132
12 Bucher HU, Killer C, Ochsner Y, Vaihinger S, Fauchère JC. Growth, developmental milestones and health problems in the first 2 years in very preterm infants compared with term infants: a population based study. Eur J Pediatr 2002;161:151–156
13 Sices L, Wilson-Costello D, Minich N, Friedman H, Hack M. Postdischarge growth failure among extremely low birth weight infants: correlates and consequences. Paediatr Child Health (Oxford) 2007;12:22–28
14 Hack M, Schluchter M, Cartar L, Rahman M, Cuttler L, Borawski E. Growth of very low birth weight infants to age 20 years. Pediatrics 2003;112(1 Pt 1):e30–e38
15 Euser AM, de Wit CC, Finken MJ, Rijken M, Wit JM. Growth of preterm born children. Horm Res 2008;70:319–328
16 Clark RH, Bloom BT, Thomas P, Peabody J. Application of the best demonstrated process method to a neonatal growth quality-improvement project. J Perinatol 2000;20:487–488
17 Morris BH, Philbin MK, Bose C. Physiological effects of sound on the newborn. J Perinatol 2000;20(8 Pt 2):S55–S60
18 Qi HX, Chen PY, Yuan SL. [Diseases in the neonatal period among preterm infants: an epidemiological investigation]. Zhongguo Dang Dai Er Ke Za Zhi 2012;14:11–14
19 American Academy of Pediatrics CoN. Nutritional needs of the premature infant. In: Pediatric Nutrition Handbook. 5th ed. Elk Grove Village, IL: American Academy of Pediatrics; 2004:23–54
20 Standley JM, Moore RS. Therapeutic effects of music and mother's voice on premature infants. Pediatr Nurs 1995;21:509–512, 574
21 Doheny L, Hurwitz S, Insoft R, Ringer S, Lahav A. Exposure to biological maternal sounds improves cardiorespiratory regulation in extremely preterm infants. J Matern Fetal Neonatal Med 2012;25:1591–1594
22 Arnon S, Shapsa A, Forman L, et al. Live music is beneficial to preterm infants in the neonatal intensive care unit environment. Birth 2006;33:131–136
23 Coleman JM, Pratt RR, Stoddard RA, Gerstmann DR, Abel H. The effects of male and female singing and speaking voices on selected physiological and behavioral measures of premature infants in the intensive care unit. International Journal of Arts Medicine 1997;5:4–11
24 Butt ML, Kisilevsky BS. Music modulates behaviour of premature infants following heel lance. Can J Nurs Res 2000;31:17–39
25 Lubetzky R, Mimouni FB, Dollberg S, Reifen R, Ashbel G, Mandel D. Effect of music by Mozart on energy expenditure in growing preterm infants. Pediatrics 2010;125:e24–e28
26 Caine J. The effects of music on the selected stress behaviors, weight, caloric and formula intake, and length of hospital stay of premature and low birth weight neonates in a newborn intensive care unit. J Music Ther 1991;28:180–192
27 Malloy GB. The relationship between maternal and musical auditory stimulation and the developmental behavior of premature infants. Birth Defects Orig Artic Ser 1979;15:81–98
28 Krueger C, Parker L, Chiu SH, Theriaque D. Maternal voice and short-term outcomes in preterm infants. Dev Psychobiol 2010;52:205–212
29 Standley JM, Cassidy J, Grant R, et al. The effect of music reinforcement for non-nutritive sucking on nipple feeding of premature infants. Pediatr Nurs 2010;36:138–145
30 Standley JM. The effect of music-reinforced nonnutritive sucking on feeding rate of premature infants. J Pediatr Nurs 2003;18:169–173
31 Richardson DK, Corcoran JD, Escobar GJ, Lee SK. SNAP-II and SNAPPE-II: Simplified newborn illness severity and mortality risk scores. J Pediatr 2001;138:92–100
32 Ruben RJ. The ontogeny of human hearing. Acta Otolaryngol 1992;112:192–196
33 Querleu D, Renard X, Boutteville C, Crepin G. Hearing by the human fetus? Semin Perinatol 1989;13:409–420
34 Panagiotidis J, Lahav A. Simulation of prenatal maternal sounds in NICU incubators: a pilot safety and feasibility study. J Matern Fetal Neonatal Med 2010;23(Suppl 3):106–109
35 Patel AL, Engstrom JL, Meier PP, Jegier BJ, Kimura RE. Calculating postnatal growth velocity in very low birth weight (VLBW) premature infants. J Perinatol 2009;29:618–622
36 Patel AL, Engstrom JL, Meier PP, Kimura RE. Accuracy of methods for calculating postnatal growth velocity for extremely low birth weight infants. Pediatrics 2005;116:1466–1473
37 Riddle WR, DonLevy SC. Generating expected growth curves and Z-scores for premature infants. J Perinatol 2010;30:741–750
38 Olusanya BO, Renner JK. Predictors of growth velocity in early infancy in a resource-poor setting. Early Hum Dev 2011;87:647–652
39 Senterre T, Rigo J. Reduction in postnatal cumulative nutritional deficit and improvement of growth in extremely preterm infants. Acta Paediatr 2012;101:e64–e70
40 Stephens BE, Walden RV, Gargus RA, et al. First-week protein and energy intakes are associated with 18-month developmental outcomes in extremely low birth weight infants. Pediatrics 2009;123:1337–1343
41 Ehrenkranz RA, Dusick AM, Vohr BR, Wright LL, Wrage LA, Poole WK. Growth in the neonatal intensive care unit influences neurodevelopmental and growth outcomes of extremely low birth weight infants. Pediatrics 2006;117:1253–1261
42 Erickson C, Kattelmann K, Remington J, et al. Traditional open-bay versus single-family room neonatal intensive care unit: a comparison of selected nutrition outcomes. Research and Reports in Neonatology 2011;1:15–20
43 Atun-Einy O, Scher A. Measuring developmentally appropriate practice in neonatal intensive care units. J Perinatol 2008;28:218–225
44 Byers JF. Components of developmental care and the evidence for their use in the NICU. MCN Am J Matern Child Nurs 2003;28:174–180; quiz 181–182
45 Carlson B, Walsh S, Wergin T, Schwarzkopf K, Ecklund S. Challenges in design and transition to a private room model in the neonatal intensive care unit. Adv Neonatal Care 2006;6:271–280
46 Stevens DC, Akram Khan M, Munson DP, Reid EJ, Helseth CC, Buggy J. The impact of architectural design upon the environmental sound and light exposure of neonates who require intensive care: an evaluation of the Boekelheide Neonatal Intensive Care Nursery. J Perinatol 2007;27(Suppl 2):S20–S28
47 Brown G. NICU noise and the preterm infant. Neonatal Netw 2009;28:165–173
48 Bremmer P, Byers JF, Kiehl E. Noise and the premature infant: physiological effects and practice implications. J Obstet Gynecol Neonatal Nurs 2003;32:447–454

49 Blackburn S. Environmental impact of the NICU on developmental outcomes. J Pediatr Nurs 1998;13:279–289
50 Wachman EM, Lahav A. The effects of noise on preterm infants in the NICU. Arch Dis Child Fetal Neonatal Ed 2011;96:F305–F309
51 Kuhn P, Zores C, Pebayle T, et al. Infants born very preterm react to variations of the acoustic environment in their incubator from a minimum signal-to-noise ratio threshold of 5 to 10 dBA. Pediatr Res 2012;71(4 Pt 1):386–392
52 Olischar M, Shoemark H, Holton T, Weninger M, Hunt RW. The influence of music on aEEG activity in neurologically healthy newborns ≥32 weeks' gestational age. Acta Paediatr 2011;100: 670–675
53 Radmacher P, Rafail S, Adamkin D. Nutrition and growth in VVLBW infants with and without bronchopulmonary dysplasia. Neonatal Intensive Care Unit 2004;16:22–26
54 Hay WW Jr. Assessing the effect of disease on nutrition of the preterm infant. Clin Biochem 1996;29:399–417
55 Morris BH, Smith KE, Swank PR, Denson SE, Landry SH. Patterns of physical and neurologic development in preterm children. J Perinatol 2002;22:31–36
56 Yeh TC, Chang JH, Kao HA, Hsu CH, Hung HY, Peng CC. Necrotizing enterocolitis in infants: clinical outcome and influence on growth and neurodevelopment. J Formos Med Assoc 2004;103: 761–766