Neonatal Intensive Care Unit Noise & Language Development*

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Some animal studies suggest that early sensory enrichment enhances neuronal function, whereas other studies suggest it impairs neuronal function. In this study, parents of 382 prematurely-born children rated the sound level of their child's neonatal intensive care unit (NICU), answered questions about their child's pre- and post-natal history and development, and assessed their linguistic and non-linguistic development. Multiple regression analyses revealed that NICU sound level was a better independent predictor of language outcome than gestational age, weight at birth or family's socio economic status, with children in louder NICUs having better language outcomes. Why might this be? Newman (2003) reports that mothers exaggerate the prosody of their speech more when they speak to their 2 year olds in noisy environments than in quiet environments. If parents in noisy NICUs exaggerate the prosodic contours of their speech, our Noise-Language findings would be consistent with phased learning theories. Our results could also be consistent with "less is more" phased learning theories if NICU noise effectively masks the phonemic, semantic, and syntactic aspects of the speech signal. Alternatively, it could be that the more-is-better theory is correct and extra auditory stimulation of any sort is beneficial for language. Preterm children receive premature exposure to both auditory and visual stimuli, and loud NICUs might simply tip the neurodevelopmental balance in favor of audition/language over vision.

1. Background

Language development in prematurely-born children. In the United States, approximately 12% of babies are born before 37 weeks gestation and 2% are born before 32 weeks gestation.[1] Children who are born preterm do worse on a wide range of speech and language tasks and are more likely to be diagnosed with written and spoken language impairments than their full-term peers.[2-13] In general, the smaller and more premature the child, the poorer his linguistic performance,[2-13] and preterm boys are more likely to suffer language impairments than preterm girls.[12-13] This paper investigates how exposure to

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developmentally inappropriate sensory stimulation in the third trimester of gestation affects preterm children's linguistic and nonlinguistic development.

By 23 to 25 weeks gestation, the cochlea is connected to the brainstem and is sufficiently mature for loud noise to produce physiological responses such as changes in human fetal heart rate, blood pressure, oxygenation and movement.[14] Thus, from 24 to 40 weeks gestation, full-term babies receive auditory stimulation but not visual stimulation. Because their mother's body selectively absorbs and attenuates frequencies above 250 Hz,[14] while in the womb, fetuses are preferentially exposed to low frequencies that correspond to prosodic aspects of language, and only after birth are they exposed to high frequencies used to convey phonemic, lexical and syntactic information. Preterm infants don't have as much opportunity for this type of phased learning. If enriched input helps (the "more is better" hypothesis), then early exposure to all speech frequencies should give the preterm infants a linguistic edge over full-term infants. At the extreme, all else being equal, preterm children should be at least as many weeks ahead of gestationally-age matched full-term children as they are premature. According to the more-is-better theory, the fact that preterm children are more likely to be language-impaired than their full-term peers underscores the fact that everything else is not equal (i.e., preterm children have more working against them than can be compensated for by extra linguistic input). If the phased learning hypothesis is correct, then, all else being equal, the more premature a child, the more linguistically delayed she should be. Enriched input could affect different aspects of language differently. For example, phonological development might be more affected (positively or negatively) than lexical or syntactic development. Alternatively, if the prosodic bootstrapping hypothesis is correct, the effects of enriched input could have cascading effects on lexical and syntactic development, with greater deficits (or benefits) for these aspects of language.

Preterm infants often spend many weeks in neonatal intensive care units (NICUs). Noise levels in modern NICUs range from 60 to 90 dB(A) with maximal sound levels of up to 120 dB(A).[15-17] Although the extra sensory stimuli that babies are exposed to in NICUs could affect NICU-graduates' auditory development, little is known about whether such stimulation actually affects their development,[16] and no published studies have investigated how the sensory environment in the NICU affects language development. With respect to auditory stimulation, in addition to hearing high frequency speech sounds prematurely, preterm infants hear unpredictable, high frequency sounds such as NICU alarms and predictable (rhythmic) high and low frequency sounds (e.g., the click of IV pumps, whosh of ventilators) that are *not* language.

Early sensory environment and development. Many studies have shown that environmental deprivation during critical postnatal periods adversely affects auditory structure and function in animals and humans, and human language does not develop normally without adequate linguistic input during sensitive periods. For example, Chang and Merzenich[18] recently demonstrated that rats exposed to 70 dB white noise from postnatal day 7 have less well-organized primary auditory cortex than rats reared in normal auditory environments. Conversely, artificially enriching the environment can positively affect neuronal structure and function in animals. For example, mute ducklings that are raised in auditory isolation have slower declines in brain stem auditory evoked potential (BAEP) thresholds and latencies of P1, especially at low and high frequencies, whereas vocal ducklings that are given enhanced embryonic exposure to species-specific calls have accelerated declines in BAEP thresholds and latencies of P1 across all frequencies, with the most marked influence on low and high frequencies.[19] Some studies have demonstrated *negative* effects of early sensory enrichment. For example, quails that receive visual stimulation prior to hatching fail to respond appropriately to maternal visual cues, continue to respond to maternal auditory cues into later stages of postnatal development and fail to learn prenatally their mother's unique call.[20- 21] Sleigh and Lickliter[21] conclude that "stimulation beyond the range of the species norm can result in intersensory interference." Turkewitz et al.[22- 23] suggest that limited *in utero* sensory stimulation, and the limited perceptual abilities of newborns enhance perceptual development are necessary for normal intermodal sensory development. In a visual preference task, 3- and 7- month old full-term babies preferred to look at a video that was synchronized with an audiotape of women reciting nursery rhymes, whereas 3- and 7- month old babies born preterm exhibited no such preference.[24] This intriguing result could either indicate that preterm babies have a general problem with intermodal integration or a more language-specific deficit. To the best of our knowledge, no animal or human studies have shown detrimental effects of enrichment <u>within</u> a sensory domain. However, work in computational neuroscience suggests that artificial neural systems develop in a more organized and efficient manner if learning is done in phases with each phase devoted to a different aspect of the learning task. For example, when Dominguez and Jacobs[25] trained artificial neural networks to detect binocular disparities between pairs of images, they found that networks initially exposed to only a subset of spatial frequencies (high or low) did better than networks exposed to all frequencies from the outset.

2. The Impact of NICU Environment on Development

Design. As part of an on-going study of perinatal risk factors associated with developmental delays, we have begun to investigate the effects of environmental noise on preterm children's development. In the Perinatal Risk Factors Study, parents who had high risk pregnancies answer questions about family demographics, pre-pregnancy health of mother, pregnancy complications and treatments, the delivery, length of hospitalization for the baby, complications and treatments the baby received in the hospital and afterwards, and when developmental milestones were achieved. If their child spent time in a NICU, parents answered questions about the NICU environment such as how brightly lit the NICU was, how noisy it was (Table 1) and how often alarms rang (Questionnaire: http://ruccs.rutgers.edu/~karin/PERINATAL/perinatal.pdf).

Table 1. How noisy was your child's NICU?

1. Quiet enough to hear and converse in whispers
2. Quiet enough to carry on a normal conversation, as if you were at home with your spouse or significant other
3. Quiet enough to carry on a normal conversation, but as if a TV or appliance was going or kids were yelling in the background.
4. Too noisy to carry on a normal conversation, so that you had to raise your voice somewhat or repeat yourself to be heard.
5. So noisy that you found yourself raising your voice, and even shouting to be heard.

Children's linguistic and non-linguistic abilities were assessed using the Ages and Stages Questionnaires (ASQ),[26] the MacArthur Communication Development Inventory (CDI) vocabulary checklists (for children under 3)[27- 28] and the Parent Assessment of Language (PAL)[29] tests (for children 3 and older). In the ASQ, parents have their children perform tasks that assess gross motor, fine motor, communication, problem solving, and social skills (e.g., http://ruccs.rutgers.edu/~karin/PERINATAL/asq-sampleforms.pdf). The PAL is a parent-administered screening test that includes sub-tests of articulation, lexical access, syntax, and reading or pre-reading skills. Articulation is assessed via a word repetition task. Lexical access is measured by a rapid naming test. Syntax is assessed by a forced-choice, picture-pointing comprehension test with semantically reversible active, passive, reflexive and pronominal sentences (e.g, http://ruccs.rutgers.edu/~karin/PERINATAL/PALS/PAL3.pdf).

Participants. We recruited monolingual English-speaking children who were the product of high-risk pregnancies by sending letters to 11 mailing lists, newsletters and bulletin boards for parents of premature children and twins. Thus far, we have sent questionnaires and assessments to parents of approximately 1200 children, and parents of 900 children have completed questionnaires and assessments for a return rate of 75%. The paper reports the effects of NICU noise levels on the 382 preterm children who spent more than one day in a NICU. The mean gestational age at birth (GA) for these participants was 31.8 +/-3.2 weeks, with 10% extremely preterm (EPT, < 27 weeks GA), 25% very preterm (VPT, < 32 weeks GA), and 65% preterm (PT, < 37 weeks). Their mean birth weight (BW) was 1705 +/- 600 grams, with 17% extremely low birthweight (ELBW < 1000 g), 18% very low birthweight (VLBW < 1500 g), 57% low birth weight (LBW, < 2500 g), and 8% normal birth weight (NBW, > 2499 g). Overall, 55% were male, and 76% were twins. At the time of assessment, the mean age of the children was 39 months, with 18% being infants (< 18 months), 40% being toddlers (18-35 months), 23% being preschoolers (36-65 months), and 18% being school-age (> 65 months). Most mothers were well educated (3% of mothers had a high school diploma or less, 18% had some post-secondary education, 46% had a bachelor's degree, and 33% had attended graduate school). Most families were affluent (10% had family incomes < 35K, 10% had incomes of 35K-49K, 35% had incomes of 50K-74K, 23% had incomes of 75K-99K, and 22% had incomes > 99K).

Outcome measures. We used 8 indices of neonatal outcome. Following Guinn et al.,[30] we used a composite index of neonatal morbidity in which 1 point is given for severe brain injury (periventricular leukomalacia or intraventricular hemorrhage, IVH, grades 3 or 4), bronchopulmonary dysplasia, necrolyzing enterocolitis, and sepsis. Neonatal neurological outcome was quantified on a 0-8 scale by adding together the IVH grade for each hemisphere (e.g., a child with no IVHs received a score of 0 and a child with bilateral grade 4 IVHs received a score of 8). The third neonatal measure was length of stay in the NICU. The fourth and fifth measures were APGAR scores at 1 and 5 minutes. The sixth measure was number of drugs given in the NICU.

The seventh measure was the total number of NICU complications. The eighth measure was length of time on a ventilator. We analyzed 21 measures of non-linguistic development. As an index of general neurodevelopmental outcome, we calculated the total amount of therapy and special educational services children received. For example, if a 4-year old had received 3 years of physical therapy (PT), 2 years of occupational therapy (OT), and 1 years of speech/language therapy (ST), he would get a score of 1.5 ((3+2+1)/4 years= 1.5 therapies/year). For gross motor abilities, we used the following 7 measures: 1) onset of sitting, 2) onset of crawling, 3) onset of walking, 4) onset of climbing stairs, 5) onset of running, 6) ASQ Gross Motor Score, and 7) amount of PT received. For fine motor abilities, we used the following 6 measures: 1) onset of scribbling, 2) onset of cutting with scissors, 3) onset of finger feeding, 4) onset of fork feeding, 5) ASQ Fine Motor Score, and 6) amount of OT received. For social development, we had 3 measures (onset of social smiling, ASQ social scores, amount of behavioral/psychological therapy). For cognitive ability, we used ASQ Problem Solving scores and the amount of special educational services[1] received as outcome measures. For non-linguistic oral motor development, the outcome measures were age at which children began to drink from an open cup and amount of feeding therapy received. Lastly, we used 10 indices of linguistic outcome: 1) onset of babbling, 2) onset of words, 3) onset of multiword utterances, 4) onset of clear articulation (articulating so that the child was understandable by strangers), 5) ASQ Communication score, 6) CDI expressive vocabulary, 7) PAL Articulation score, 8) PAL Syntax score, 9) PAL Lexical Access score, and 10) amount of speech/language therapy (ST) received. For all measures, we used gestationally-corrected age not chronological age.

3. Results

NICU noise analyses. Multiple regression analyses with NICU sound levels, gestational age (GA) and birth weights (BW) as regressors revealed that NICU sound was a significant independent predictor for 6 of the 10 linguistic measures, with preterm children in louder NICUs having *better* linguistic outcomes than those in quieter NICUs. Specifically, children in louder NICUs scored *higher* on 2 language tests (<u>ASQ communication</u> beta = +.26, $t(194) = 3.66$, $p = .0003$; <u>PAL</u>

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[1] This included remedial instruction, resource room, an instructional aide, full- or part-time enrollment in a special education classroom, and repeating a grade.

articulation beta = +.17, *t*(150) = 2.02. *p* = .04), achieved 3 linguistic milestones *earlier* (babbling beta = -.18, *t*(267) = 2.82, *p* = .005, first words beta = -.13, *t*(269) = 2.09, *p* = .04; first sentences beta = -.14, *t*(214) = 2.03 *p* = .04), and required *less* ST (beta = -.11, *t*(377) = 2.18, *p* = .03).[2] GA was only a significant independent predictor for one language measure, with lower GA being associated with more ST (beta = -.33, *t*(377) = 3.57, *p* = .0004). BW was also only a significant independent predictor for one language measure, with lower BW being associated with lower PAL syntax scores (beta = +.29, *t*(150) = 2.09, *p* = .04).

Multiple regression analyses performed on the 29 non-linguistic measures indicate that language development is selectively enhanced by NICU noise. NICU sound was a significant independent predictor for 1 of the 7 gross motor measures (with children in noisier NICUs running at earlier ages, beta = -.15, *t*(235) = 2.31, *p* = .02) and 1 of 6 fine motor measures (with children in noisier NICUs fork-feeding at late ages, beta = +.22, *t*(236) = 3.61, *p* = .0004). Children in noisier NICUs had greater composite neonatal morbidity scores (beta = .12, *t*(378) = 2.67, *p* = .008), one of 8 measures of neonatal outcome. Whereas GA was only a significant independent predictor for 1 of 10 linguistic outcome measures, GA was a significant independent predictor for the majority of nonlinguistic measures. Specifically, GA was a significant predictor for 6 of 8 measures of neonatal outcome (brain injuries, neonatal morbidity, 1 and 5 minute APGAR scores, length of NICU stay, and number of drugs received in the NICU), 3 of 7 gross motor measures (onset of sitting and crawling, and amount of PT received), 3 of 6 fine motor measures (onset of finger-feeding and fork feeding and amount of OT received), 1 of 2 oral motor measures (amount of feeding therapy received), 1 of 2 cognitive measures (amount of special education services received), 1 of 3 social measures (onset of social smiling), and our 1 measure of overall long-term outcome (total amount of special services and therapies received). In all cases, higher GA was associated

[2] Degrees of freedom vary for several reasons. Some parents didn't remember when their child achieved a milestone and some children had yet to achieve a milestone. For some therapy measures, some children were excluded because they were too young to have the therapy (e.g., children who were less than 3 were excluded from the behavioral /psychological therapy and special education measures). For ASQ measures, we excluded children who took the ASQ more than one month early or late. For tests, degrees of freedom also varied depending on the number of children who were the right age to take the test (e.g., children under 3 didn't take the PAL).

with better nonlinguistic outcome. BW was a significant independent predictor for only 1 nonlinguistic measure, with higher BW children beginning to walk at an earlier age than lower BW children.

NICU alarm analyses. Although NICU sound levels and alarm frequency were significantly correlated ($r = +.23$, $t(371) = 2.88$, $p < .00005$), the correlation coefficient was not so high as to obviate the need to perform alarm analyses. Therefore, we performed multiple regression analyses of outcome measures using frequency of NICU alarms, GA and BW as regressors. These analyses revealed that GA was generally the best independent predictor of outcome, with higher GA predicting better outcome for 1 linguistic measure (speech therapy beta = -.30, $t(368) = 3.34$, $p = .0009$), 7 out of 8 neonatal measures (the exception being total number of complications), 4 of 7 gross motor measures (onset of sitting and crawling, ASQ gross motor scores, and amount of PT received), 4 of 6 fine motor measures (onset of scribbling, finger feeding, and fork feeding, and amount of OT received), 1 of 3 social measures (onset of social smiling), 1 of 2 cognitive measures (amount of special educational services received), 1 of 2 oral motor measures (amount of feeding therapy received), and the one measure of overall neurodevelopmental outcome (total amount of special therapies and services received). Alarm frequency was not a significant independent predictor for any of the 10 linguistic measures, and was only a significant independent predictor for 2 of the 29 nonlinguistic measures, with more alarms being associated with later onset of social smiling (beta = +.14, $t(306) = .009$) and more feeding therapy (beta = +.12, $t(368)$, $p = .01$). BW was not a significant independent predictor for any measure.

NICU light analyses. Although NICU sound levels and NICU light levels were moderately correlated ($r = +.34$, $t(297) = 37.72$, $p < .00005$), multiple regression analyses with NICU light levels, GA and BW as regressors revealed that light levels were not as predictive of language outcome as sound levels. Whereas NICU sound level was a significant independent predictor for 6 of 10 language measures, NICU light level was a significant independent predictor for only 1 language measure (greater light levels were associated with higher ASQ communication scores beta = +.14, $t(194) = 2.00$, $p = .05$). Light and sound also behaved differently as predictors of nonlinguistic measures. As discussed above, greater NICU sound level was associated with earlier onset of 1 gross motor milestone and later onset of 1 fine motor milestone. On the hand, brighter NICUs were associated with delays in crawling, walking, and fork-feeding. GA's predictive power was virtually the same in sound, alarm and light multiple regression analyses. In the light analyses, GA was an independent predictor for 1 language measure (amount of ST received), 4 of the 7 gross motor measures (the 3 measures that were significant in the sound analyses plus onset of walking), 4 of the 6 fine motor measures (the 3 measures that were significant in the sound analyses, plus onset of scribbling), 1 of the 2 oral motor measures (the same one that was significant in the sound analyses), 1 of the 3 social measures (the same one that was significant in the sound analyses), 1 of the 2 cognitive measures (the same one that was significant in the sound analyses), and our 1 measure of overall long-term neurodevelopmental outcome (also significant in the sound analysis), and 7 of 8 neonatal measures (the 6 neonatal measures that were significant in the sound analyses plus length of time on a ventilator).

Are the noise-language results real? Only NICU noise level was a significant independent predictor for a majority of our language measures. To investigate whether the beneficial effect of increased NICU noise on language is real or the result of a confounding factor, we analyzed the relationship between NICU noise levels and factors that have been shown to affect preterm children's linguistic development. Some studies have shown that family and socio-economic status (SES) factors impact language development in preterm children.[31-35] Perhaps children in louder NICUs had fewer social risk factors than children in quieter NICUs. Our analyses suggest this is not the case. NICU noise ratings were not significantly correlated with parents' age or SES (a composite of parents' education and family income). To further investigate the effects of SES on linguistic and nonlinguistic outcome, we performed multiple regression analyses with GA, BW, Noise and SES as regressors. Even when SES was added, Noise remained a significant independent predictor for 5 linguistic measures (babble, words, sentences, ASQ communication, and ST), with more noise being associated with better outcomes. SES was a significant independent predictor for 3 linguistic measures (CDI expressive vocabulary, PAL articulation, and ASQ communication scores, with Noise being the better predictor of ASQ communication scores), and 8 nonlinguistic measures (ASQ gross motor, fine motor, problem solving, and social scores, neonatal morbidity, 1 minute APGAR scores, amount of behavioral/psychological therapy and onset of sitting). In all cases, higher SES was associated with better outcome.

Because some researchers have shown that premature infants who receive human breast milk have better developmental outcomes than those who receive formula,[36- 37] we performed a simple regression analyses to determine whether NICU noise level was correlated with amount of human breast milk received. It was not. Because in a previous study, we found that prenatal exposure to glucocorticosteroids (GCs) selectively impacted language development,[38] we checked whether there was a relationship between NICU noise levels and prenatal steroid exposure. We found none. The correlation between NICU noise level and steroid dose was not significant and an ANOVA revealed no effect of steroid group on Noise levels. Longitudinal studies have generally found that the discrepancy between full-term and preterm children becomes more apparent as children get older.[8- 11] If older children were more likely to be in quieter NICUs, this could account for the apparent benefit of loud NICUs. This doesn't appear to be the explanation because NICU noise and children's ages were not correlated.

Perhaps children who were in louder NICUs were healthier than those in quieter NICUs. This does not appear to be the case. In fact, simple regression analyses revealed that children who were in noisier NICUs were significantly smaller (r = -.20, $t(380)$ = 16.19, p = .0001), more premature (r = -.20, $t(380)$ = 16.55, p = .0001) and sicker during the neonatal period (as measured by brain damage scores, neonatal morbidity scores, 1 minute APGAR scores, days in the NICU, days on a ventilator) than children in quieter NICUs. ANOVAs with children's sex, handedness, hearing status, and neonatal jaundice (a risk factor for hearing loss) as between subjects factors revealed no significant group differences in NICU noise ratings. An ANOVA did reveal that twins were in significantly quieter NICUs than singletons (mean Noise rating for twins = 2.31, mean Noise rating for singletons = 1.78, $F(1, 380)$ = 34.28, $p < .0005$).

NICU noise and twins' outcome. Twins' language development often lags behind that of singletons.[39-46] Given this, perhaps our Noise-Language findings are due to twins' having been in quieter NICUs than singletons. To investigate this possibility, we redid the multiple regression analyses including only data from twins. The results were even 'cleaner': NICU sound was a significant independent predictor of better outcome for 7 of the 10 linguistic measures. Twins in louder NICUs did better on 2 language tests (<u>ASQ communication</u> beta = +.27, $t(153)$ = 3.48, p = .0006; <u>PAL articulation</u> beta = +.29, $t(103)$ = 3.09, p = .003), achieved all 4 linguistic milestones earlier (<u>babbling</u> beta = -.31, $t(198)$ = 4.56, $p < .00005$, <u>words</u> beta = -.21, $t(197)$ = 3.07, p = .002; <u>sentences</u> beta = -.19, $t(153)$ = 2.40 p = .02; <u>clear articulation</u> beta = -.15, $t(157)$ = 1.96, p = .05), and required less ST (beta = -.18, $t(284)$ = 3.22, p = .001). As was the case when singletons were included in analyses, GA was only a significant independent predictor for 1 language measure (with lower GA twins receiving more ST, beta = -.31, $t(284) = 3.51$, $p = .0005$) and BW was only a significant independent predictor for one language measure (with lower BW twins having lower PAL syntax scores, beta = +.31, $t(102) = 2.43$, $p = .02$).

Multiple regression analyses performed on the twins' 29 non-linguistic measures indicate that twins' language development is selectively enhanced by NICU noise. Noise was a significant independent predictor for only 1 fine motor measures, with twins in noisier NICUs beginning to scribble at earlier ages (beta = -.22, $t(156) = 2.93$, $p = .004$). Although twins in noisier NICUs had more serious neonatal complications (as measured by the composite neonatal morbidity scores, beta = .11, $t(285) = 2.13$, $p = .03$), they suffered from fewer complications in the NICU (beta = -.15, $t(285) = 2.54$, $p = .01$), suggesting that twins in noisier NICUs suffered fewer minor complications. Whereas GA was only an independent predictor for 1 of 10 linguistic measures, GA was a significant independent predictor for the majority of the twins' 29 nonlinguistic measures. GA was a significant predictor for 6 of 8 neonatal measures (brain injuries, neonatal morbidity, 1 and 5 minute APGAR scores, length of NICU stay, and number of drugs received in the NICU), 4 of 7 gross motor measures (onset of sitting, crawling, and walking and amount of PT received), 3 of 6 fine motor measures (onset of scribbling and cutting with scissors, and amount of OT received), 1 of 2 oral motor measures (amount of feeding therapy received), 1 of 3 social measures (onset of social smiling), and our measure of overall long-term neurodevelopmental outcome. In all cases, higher GA was associated with better outcome. BW was a significant independent predictor for only 1 nonlinguistic measure (higher BW was associated with earlier finger-feeding).

4. Discussion

Why does exposure to more NICU noise selectively enhance language development? We considered and rejected the possibility that children in louder NICUs had fewer risk factors for language delay. In general, there were no significant correlations between NICU sound levels and variables that have been shown impact preterm children' language development. There *were* significant correlations between NICU sound levels and some biological risk factors. However, infants in noisier NICUs were sicker, smaller, and more premature than infants in quieter NICUs. In other words, from a biological risk factor standpoint, children in noisier NICUs should have had worse language outcomes than children in quieter NICUs. The fact that they had *better* outcomes indicates that NICU sound level (or something correlated with NICU sound level) has a very powerful (and selective) effect on language. Perhaps louder NICUs provided better clinical care than quieter NICUs. For example, louder NICUs might be larger, and larger NICUs may be better at treating sick neonates. Or perhaps the NICUs were louder because they have more equipment or staff. The problem with the Louder NICU = Better NICU explanation is that it predicts that children in louder NICUs should have better linguistic and nonlinguistic outcomes. However, being in a louder NICU was associated with better linguistic outcome but not better nonlinguistic outcome. It is unlikely that the Noise-Language results are due to a Noise-SES confound because NICU noise ratings were not correlated with SES. In addition, multiple regression analyses suggest that Noise selectively affected linguistic development, whereas SES affected non-linguistic development as much or more than linguistic development. Perhaps parents who reported louder NICU levels were more bothered by the noise because they spent more time in the NICU visiting their child. In other words, NICU noise levels could be a proxy for parental involvement and/or attachment. The problem with this explanation is that parental involvement/attachment should affect all aspects of development and not just linguistic development.

Some studies have shown positive correlations between the amount (or type) of adult speech that children hear and children's language development. Perhaps NICU noise ratings are an indirect measure of how inclined parents are to talk (i.e., parents who reported louder NICU sound levels are more talkative and, hence, found NICU noise more disruptive). Newman[47] reports that mothers exaggerate the prosody of their speech more when they speak to their 2 year olds in noisy environments than in quiet environments. If parents in noisy NICUs exaggerate the prosodic contours of their speech, our Noise-Language findings would be consistent with phased learning theories. Similarly, if the distribution of sound in noisy NICUs is broad-spectrum (or high-frequency weighted) white noise, NICU noise could block neonates' exposure to phonemic, semantic, and syntactic information which babies are not exposed to in the womb. In other words, NICU noise could effectively mask the phonemic, semantic, and syntactic aspects of the speech signal. Alternatively, it could be that the more-is-better theory is correct and extra auditory stimulation of any sort is beneficial for language. Preterm children receive premature exposure to both auditory and visual stimuli, and loud NICUs might simply tip the neurodevelopmental balance in favor of audition/language over vision. To really answer the questions of how and why acoustic input in the third trimester of gestation affects language development, we will need a prospective, carefully-controlled study of auditory and linguistic development of children from whom we have detailed information about early acoustic experiences.

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