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REVIEW ARTICLE

Impact of the NICU environment on language deprivation in preterm infants

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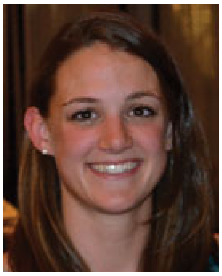

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ABSTRACT
It is unclear whether the atypical language development commonly seen in preterm infants is a consequence of language deficiency experienced during their prolonged NICU stay. This review provides a novel viewpoint, which highlights the potential impact of the NICU design on the developmental origin of language disabilities in preterm infants.

Conclusion: Further research is needed to identify evidence-based design solutions for providing preterm infants with a healthier linguistic hospital environment that aids growth and development.

ATYPICAL LANGUAGE DEVELOPMENT IN PRETERM INFANTS

Premature birth often leads to compromised neurodevelopment (1–3). One primary problem evident in the preterm population is atypical language development. Studies have shown that infants born very prematurely (<32 weeks of gestation) with a very low birth weight (<1500 g) are more likely to have cognitive and language difficulties prior to school age (4). Compared to full-term newborns, preterm infants are more likely to display setbacks and disabilities in early communicative gestures as well as in lexical and grammatical performance at 24 months corrected age (5). In addition, when tested at 12 months of age, infants born prematurely have demonstrated atypical perceptual narrowing indicated by delayed phoneme discrimination (6) and poor expressive language abilities (7). Even in the absence of a known brain injury, approximately 25–30% of preterm infants experience difficulties in language acquisition, which at school age often surface as general behavioural emotional problems, poor verbal comprehension, attention deficits and lower intelligence quotient (IQ) (8–11). A recent meta-analysis reviewing 17 studies on this topic demonstrated that preterm-born children (aged 3–12) have increased difficulties with both simple and complex language function, and that those difficulties were independent of major disabilities and socioeconomic status (12). Brain imaging studies have shown that neonatal white matter abnormalities at term equivalent age correlated with preterm infant's neurocognitive outcomes (13) and expressive language assessments (14) at preschool age. White matter abnormalities have also been associated with language subdomains of phonological awareness, semantics, grammar and discourse, but not pragmatics (15).

Key notes

- Both the incubator and single-room NICU design increase social isolation, cause language deprivation and may heighten the risk of atypical language development.
- Most human conversations in a multibed NICU design are blocked by ambient noise, depriving the infant of meaningful language stimulation.
- Exposure to human speech during the neonatal period, especially mother's voice, adds linguistic value that can be crucial for the initial wiring of the brain for language acquisition.

PRENATAL EXPOSURE TO MATERNAL SPEECH SOUNDS AS A PRIMER FOR POSTNATAL LANGUAGE DEVELOPMENT

The foetal capacity to hear and respond to sounds demonstrates that auditory attention, memory and language abilities originate before birth (16). At approximately 25 weeks of gestation, the foetus can already perceive and respond to speech sounds (17). Beyond 26 weeks of gestation, hair cells in the cochlea can translate vibratory acoustic stimuli into an electrical signal that is sent to the brainstem and become fine-tuned for specific frequencies, especially in the lower range (18,19). In the last trimester of pregnancy, the human brain is mature enough to distinguish between different sounds (20). Leading studies from Kisilevsky's laboratory have shown that foetuses selectively respond to their mother's voice with detectable changes in heart rate as early as 32 weeks of gestation (21–23). The neural correlate of this response was recently revealed by foetal brain imaging, demonstrating significant cortical sensory activation *in utero* between 33 and 34 weeks of gestation (24). Near-term foetuses are capable of perceiving pitch and temporal features of speech and develop auditory memories that can last at least 6 weeks after birth (25,26). These studies give rise to the hypothesis that early experience with mother's voice has enduring effects on the developing brain and may wire the foetus for language processing and word learning ability soon after birth.

The prenatal response to mother's voice continues postnatally. Newborn infants show many perceptual sensitivities in response to spoken language that are indicative of a familiarity with the stimulus (27). In fact, when tested after birth, infants actually prefer their mother's voice over an unknown female's voice as indicated by selective changes in heart rate (16), non-nutritive sucking (28) and orienting movements towards the source of the sound (29). Interestingly, newborn infants cannot only identify the voice of the speaker (i.e. mother vs. nonmother) but also show preference to the type of language used (i.e. native vs. foreign) based on their individual language experience *in utero* (30). Similarly, newborns whose mothers spoke only English during pregnancy showed a robust preference for English, whereas newborns of bilingual mothers showed equal preference for both languages (31). The idea that prenatal bilingual exposure affects infants' preferences was validated in an optical imaging study in newborn infants (0–5 days old), demonstrating that the neural activity in response to familiar and unfamiliar languages is modulated by prenatal language experience (32). Taken together, exposure to maternal speech sounds, during both the prenatal and early postnatal periods, ensures that the foetus/infant is provided with the educational resources necessary for normal language development.

AUDITORY DEPRIVATION ALTERS NEURODEVELOPMENT

Acoustic stimulation very early in life is known to significantly impact the functional development of the auditory brain system (33). Evidence for this profound effect is primarily derived from animal studies. For example, juvenile birds raised under severe auditory deprivation showed significant delays in topographic brain circuitry (34). Similarly, prolonged auditory deprivation has been shown to decrease the expression levels of selective NMDA receptors in the rat auditory cortex during early postnatal development (35). In addition, evidence from congenitally deaf animals suggests that a deprived auditory cortex will display atypical development and degenerate due to missing auditory input (36). Rat pups raised under sensory deafness conditions have been shown to develop abnormal synaptic morphology in the primary auditory cortex, in terms of dendritic shape, length and spine density (37). In contrast, exposing infant rat pups to an enriched auditory environment enhanced their auditory discrimination and learning abilities (38). An established body of work by Lickliter and colleagues has shown that bobwhite quail chicks receiving auditory stimulation early in embryogenesis, as well as during the first 72 h following hatching, display atypical visual responsiveness when tested postnatally (39). These results suggest that prenatal auditory stimulation can go beyond auditory plasticity to also affect the development of the visual system owing to the intersensory nature of sensory brain development.

LANGUAGE DEPRIVATION IMPOSED BY THE NICU ENVIRONMENT

Preterm infants in the NICU are not necessarily deprived of auditory stimulation in the same clear-cut manner as the animals studies mentioned above. Unlike an experimental setting, in which a researcher can create a completely deprived environmental condition, studying human neonates does not allow for such extreme experimental manipulations due to legitimate ethical considerations.

In practice, there are two possible scenarios that can cause language deprivation in the NICU environment (Fig. 1). In the first scenario ('too quiet'), the infant is placed in an incubator, in a private room with limited human traffic, wherein language stimuli are significantly attenuated by the incubator walls (Fig. 1A). In the second scenario ('too loud'), the infant is placed in an open-air crib, in a multibed, open-bay NICU, wherein the simultaneous perception of asynchronous human voices (e.g. doctors, nurses, parents and visitors) over random electronic sounds coming from ventilators, monitors and alarms essentially boils down to a constant stream of noise that prevents meaningful language exposure from reaching the infant's ears (Fig. 1B). In this case, the infant is not completely deprived of auditory stimulation; however, sounds are not specifically directed to the infant but only happening around him/her. Thus, the infant may have opportunities to develop basic auditory abilities, but not necessarily specific, essential speech and language-processing skills.

Single room vs. open-bay design

Over the past decade, an increasing number of hospitals have switched from the traditional multibed, open-bay NICU design to single-family rooms. The motivation for transition is largely twofold – to promote family-centred

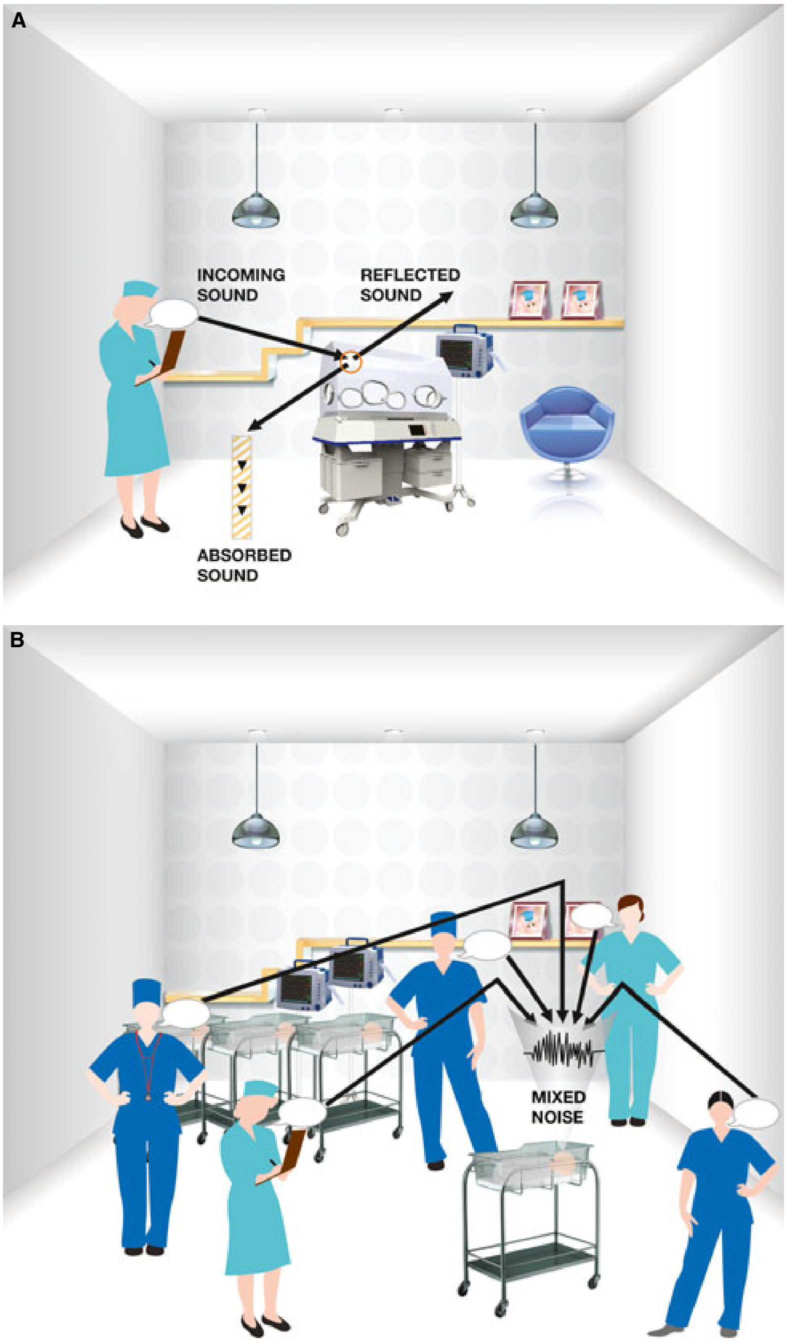

Figure 1 The seemingly protective setting provided by both the incubator and the single-room NICU design increases social isolation, causes language deprivation and may heighten the risk of atypical language development. Shown are two developmental scenarios that demonstrate language deprivation in the NICU. (A) In the first scenario ('too quiet'), the infant is placed in an incubator, in a private room with limited human traffic, wherein language stimuli are significantly attenuated and absorbed by the incubators walls. Thus, a seemingly superior private family suite can become a deprived environment, if parents are not actively engaging, talking, reading or singing to their infants during visitation time. (B). In the second scenario ('too loud'), the infant is placed in an open-air crib, in a multibed, open-bay NICU, wherein the simultaneous perception of random human voices over electronic sounds coming from ventilators, monitors and alarms essentially boils down to a constant stream of noise that prevents meaningful language exposure from reaching the infant's ears.

care (40) and to limit the amount of toxic noise exposure (41). Although the single-family room model seems very compelling, it brings about several challenges including decreased patient visibility, insufficient staff coverage and limited communication between parents and medical personnel (42,43). However, overall, recent discussions assert that the benefits, such as promoting family-centred care, increasing privacy and confidentiality, increasing visitation time, raising parent satisfaction and decreasing parental stress, although controversial (44), appear to outweigh the challenges. While the single-family room model is growing in popularity, the NICU community has largely overlooked the possibility that this model increases social isolation and worsens the problems of language deprivation. A seemingly superior private family suite can become a deprived environment, if parents are not actively engaging, talking, reading or singing to their infants during visitation time.

Unlike the single-family room, the open-bay design facilitates communication and social interactions between parents, caregivers and medical personnel while monitoring multiple infants over a small area. A by-product of these care practices is a greater amount of human conversations. However, the vast majority of these human conversations are essentially blocked by the high level of ambient noise in the NICU environment, leaving the infant deprived of meaningful language stimulation. Recent work by Vohr and colleagues, using the Language Environment Analysis (LENA) system, demonstrated that only 2–5% of the sound environment that preterm infants are exposed to in an open-bay NICU consists of identifiable adult language (45). Thus, from the infant standpoint, the simultaneous exposure to indirect human voices over electronic sounds coming from ventilators, monitors and alarms is essentially perceived only as a chaotic collage of noises as one would experience while in a crowd or on a busy flight (46). In fact, Caskey et al. (45) have also shown that about two-thirds of the sound environment in an open-bay NICU is composed of monitor sounds and background noise. Considering that the capacity to separate speech from different speakers in the context of noise (known also as the 'cocktail party effect') is extremely limited in infancy and only develops around 1 year of age, it is reasonable to question whether preterm infants can gain substantial linguistic benefits from the noisy environment of an open-bay NICU (47).

Incubators vs. open-air cribs

In an open-air crib, NICU infants are exposed to a greater number and variety of voices and sounds, and thus, one may assume that an incubator provides a healthier sound environment. Indeed, the NICU incubator serves as an important shelter to ease the transition to the extrauterine world. However, whether in a single-family or open-bay NICU, the seemingly protective noise attenuation provided by the incubator walls (48) isolates the infant from human speech sounds, thereby causing significant language deficiency. As a result, while in the incubator, preterm infants are missing crucial opportunities to process speech sounds as they would otherwise be able *in utero*. The lack of opportunities to process linguistically meaningful auditory input from inside the incubator can have a profound effect on the initial organisation of language centres of the brain and subsequent speech and language acquisition.

ADDRESSING THE PROBLEM OF LANGUAGE DEPRIVATION IN THE NICU: CURRENT AND FUTURE DIRECTIONS

This paper introduces the idea that the language environment in the NICU is developmentally suboptimal and, as such, may account, at least in part, for future cognitive and language deficits. However, one should bear in mind that a variety of confounding factors, such as prenatal insults, pregnancy complications and other morbidities resulting from being born prematurely, can possibly co-contribute to atypical language development commonly seen in NICU graduates. Given a growing of body of literature that echoes with our concerns about the language environment in the NICU, here, we urge consideration of the following suggestions for increasing language exposure for preterm infants.

Reduce noise levels

Aside from the adverse effects of noise on preterm infants, for review (49), noise is also a major source of masking direct language stimulation. Open-bay units should consider environmental adaptations for decreasing ambient noise such as modifying equipment, introducing silent alarms, increasing staff awareness, installing sound absorbing materials and routinely monitoring noise levels (50,51).

Encourage NICU parents to speak to their infants when visiting

Studies have shown that NICU infants are more likely to vocalise in the presence of a parent or a caregiver talking to them. The number of such reciprocal vocalisations per hour increased by 520% at 32 weeks and by 160% at 36 weeks, when a parent was visiting and interacting with their infant (45,52). These findings highlight the early interaction through language that is occurring with preterm infants and their parents, suggesting that what parents do during their visit does matter. Because *asynchronous* speech sounds serve only as background noise, education programmes should encourage both NICU parents and caregivers to emphasise *synchronous*, infant-directed speech as early as 26–28 weeks gestation when myelination of axons is initiated in the auditory brainstem pathway (53). This should be carefully implemented within principles of family-centred developmental care (54) as a way of increasing the sensory quality and developmental value of parents' visitation (55).

Incorporate recorded maternal sounds during nonvisitation hours

Recent studies have shown that exposure to maternal voice can significantly increase oxygen saturation (56), decrease apnoea and bradycardia events (57) and improve weight gain (58) and feeding tolerance (59). Although research in this area is still developing, these results are of clinical relevance because correlations have been drawn linking early feeding outcomes and respiratory stability with language skills later in life (60). Thus, in addition to the potential short-term benefits on physiological stability and growth, the use of recorded maternal sounds as a supplement to, not a replacement of, parental visits provides an additional element in neonatal care, expanding opportunities for maternal speech exposure even when the mother is not physically present.

SUMMARY

This article argues that the lack of sufficient opportunities to perceive maternal speech sounds during prolonged NICU stay can alter language development in preterm newborns. The impact of NICU design on speech and language development has been understudied and warrants further investigation. Although language deficits are very common among preterm infants, there are still some infants whose language development eventually falls within the normal range. This suggests that even with a period of language deprivation during NICU stay, there is still opportunity for recovery. It is still unclear whether or not there is a critical window for language exposure; however, the common understanding is that exposing preterm newborns to speech stimuli should start early enough to ensure optimal wiring of the brain for language. Further research is needed to examine whether carefully prescribed exposure to linguistic stimuli in the neonatal period can improve long-term language and communication outcomes in NICU graduates, possibly preventing learning disabilities in this population.

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