Chapter 11
Recorded Maternal Voice, Recorded Music, or Live Intervention: A Bioecological Perspective

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Abstract *Introduction*: The human infant develops in his or her expected bioecological niche based on experience-dependent regulation of physiology, motor control, and arousal, typically provided by close contact with the mother. Synchrony, intensity, tempo, and rhythm of a mother's physical and vocal communication are embedded in what the infant experiences and lay the foundation for attachment relationships and optimal development. Infants who have significant medical issues or are early born experience a different developmental niche than would a typically developing infant. This chapter addresses the complexities of exposure of the newborn in intensive care to different models of intimate caregiving, including the mother's recorded or live voice and recorded or live music, in the context of current knowledge of necessary species-specific, co-regulatory synchronous interactions. Additionally, the chapter explores opportunities and barriers to the provision of optimal mother-infant communication in intensive care.

Aims: The aims of this chapter are to describe foundational developmental science that contributes to our understanding of the components of optimal bioecological niches for developing infants in the NICU and to provide a rationale for promoting optimal intersensory, redundant, synchronous, and rhythmic experiences for the developing infant through the mother's presence. Additionally, an aim of the chapter is to examine current intervention strategies that may or may not provide optimal bioecological niches for developing infants under intensive care.

Conclusions: Developmental science contributes to our emerging understanding of the optimal bioecological niche for the developing infant. Medically fragile and/or early born infants are thought to have over or underexposure to sensory experiences prompting the addition of live and/or recorded inputs such as the mother's

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voice or music and other multisensory stimulation approaches. Research on such interventions has begun to explore their benefits and/or challenges, but findings are not consistently conclusive. From a developmental science and clinical research perspective, the likely most optimal niche for the developing infant is the mother's body and voice. NICU practices that encourage mothers to be with and communicate with their baby need to be promoted.

Underpinnings of an Ecological Perspective

The Infant's Ecological Niche

All human infants are born within the context of his or her parents, the extended family and the culture in which they live. The "developmental niche" is a framework for understanding the cultural microenvironment of the baby. Three subsystems have been identified and are used to understand the child's functioning within his or her personal developmental niche: the physical and social setting, customs of child care, and psychology of the caregivers (Super & Harkness, 1994). Infants who have significant medical issues or are early born experience a different developmental niche than would a typically developing infant.

Physical and social settings refer to interactions with people who determine the kind of environments infants are exposed to, as well as provision of nurturing social relationships that are elicited by the infant. Infants who experience a newborn intensive care unit (NICU) stay have a vastly different physical environment and social interactions due to medical interventions and specialized hospital care from that of infants who are born to and live in their family home (e.g., lighting, bedding, medical rounds, parental "visiting" restrictions).

Customs of child care are sequences of behavior common to members of the community and so embedded in the larger community that they need no particular rationale or conscious thought. NICU and hospital caregiving is often challenging for the newborn; however, routines and caregiving rituals of the NICU have become regimented and customary (e.g., the "ritual" of bathing infants in the middle of the night, the routine of blood drawn in the early morning hours, or diaper change and vital signs before being fed).

Psychology of the caregivers includes beliefs concerning the nature and needs of children, and the organizing parenting strategies of child rearing. Caregiver psychology provides an immediate structure to the children's development through the meaning it invests in universal behaviors and processes. In the NICU, caregiving may be influenced by different philosophies of care for infants (e.g., the perspective that infants do not perceive pain or infants do not have the capacity for emotions) and the lack of parental presence to guide their own child's caregiving.

The developmental niche of the newborn is embedded in and influenced by both the altered environment in which they live and the customs, rituals, and psychology of their various caregivers.

Gottfried and Gaiter, in their seminal book *Infant Stress Under Intensive Care*, coined the term "environmental neonatology" and stressed the importance of attending to the ecology of the NICU (Gottfried & Gaiter, 1985). In their description of the NICU environment in the 1980s, Linn et al. (Linn, Horowitz, Buddin, Leake, & Fox, 1985) described typical interactions, contingent responses during interactions, and state availability of the infant for communication that constitute the ecology of the newborn in the NICU. These initial studies focused on an aspect of the ecology of the newborn that had not been emphasized previously and began a larger view of the experience of the newborn in the NICU in terms of the impact of the physical and social environment, as well as the caregiving on infant development.

The Bioecological Perspective of Infant Development

Bronfenbrenner is known best for the development of the ecological theory of development that focuses primarily on the context in which a child develops. These include microsystems or the most proximal setting where the child develops; mesosystems, which are made up of two or more microsystems; exosystems which involve the politics and society's social policies; and macrosystems which are composed of economic, social, education, legal, and political systems (Rosa & Tudge, 2013). His shift from the term "ecology" to "bioecology" was to emphasize the participation of the individual in his or her own development (Bronfenbrenner & Ceci, 1994). The central aspect of his theoretical perspective is that of "proximal processes" which are considered the primary driving force in development (Rosa & Tudge, 2013). Proximal processes have four components, those of process, person, context, and time, which work interdependently.

Bronfenbrenner's bioecological framework serves to explain the integration of interactions of infants in the context of his or her personal characteristics, environment in which they develop, their family interactions, and the larger family culture. The newborn in the NICU can be seen to develop within his or her bioecological context that includes not only their own personal makeup (e.g., temperament, resilience) but also an altered physiological status (e.g., preterm birth, medical complications, reliance on technology). They also are born into a family that is also in an altered psychological state in addition to being in a very unexpected environment and NICU culture. Proximal processes are thus different from what might be expected had the infant been born into a more typical family, environment, and culture.

Experience Expectance and Dependence as a Foundation of Bioecology of the Newborn

Infant development is organized around neurodevelopmental expectations and changes that are either "experience expected" or "experience dependent." Greenough and colleagues (Greenough, Black, & Wallace, 1987) defined "experience expectant" brain development as common to all species, which is organized for expected environmental input. It can be viewed as neural preparation for incorporating specific information, for example, fetal to newborn maternal voice recognition. "Experience-dependent" brain development is when active formation of new synaptic connections is made in response to events that an infant experiences that provide information to be stored, for example, the physical sound environment or the specific vocabulary that a mother uses when she talks to the infant. These constructs are used to further explain the underlying mechanisms for how the infant's brain development has "plasticity" as in the definition of "critical" or "sensitive" periods during which they are sensitive to specific environmental input or lack thereof.

Sensory development of the preterm infant proceeds in a stepwise fashion and, depending on the stage of development they are in, may be impacted by inappropriate, mistimed, or overwhelming sensory inputs. Developing in a cacophonous NICU environment presents challenges to experience-dependent sensory integration (Lickliter, 2011).

Hidden Regulators as the Bioecological Underpinnings of Early Interactions and Attachment

Bioecology of the newborn can serve to explain the context in which infant development occurs. Infant development is most impacted by the microsystem where interactions with parents and caregivers provide physiological, sensory, social, psychological, and cultural foundations for growth. The developmental niche or bioecology of the newborn in the NICU is altered from what might be expected, as their micro- and mesosystems are significantly different from those experienced by the nonhospitalized newborn. One microsystem is that of the physical or "distal" environment such as sound, light, activity, drafts, odors, and visual array. Another is the interactional or "proximal" environment of movement when cared for, tactile sensations of bedding and touch, verbal communication, odor within the bed space, taste of food or medications, and visual opportunities during interaction. Within the proximal microsystem are the more qualitative interactions or proximal processes of nurturing, caring, and emotional and verbal exchange. All microsystems impact the development of the newborn in the NICU, but likely the most essential for their experience expectant brain is the intimate proximal interactions that are offered by the infant's mother and primary caregivers. These interactions can be seen as providing regulation of physiology, state, and movement to the infant and as assuring a

sound foundation for later attachment relationships that are essential for optimal development (Bowlby, 1954, 1958, 1968; Hofer, 1994).

Mothers, as the most intimate and important microsystem for the developing infant, provide regulatory mechanisms for infant stability. Hofer (Hofer, 1994) has proposed that many of these regulators are hidden to view and are provided in typical interactions during feeding, play, and caregiving. Hidden regulators control the behavioral, autonomic, endocrine, and sleep-wake states of the infant and thus control the parts of the early emotion states associated with attachment, separation, and loss first described by Bowlby (Bowlby, 1982; Hofer, 1994). Interactions between the mother and infant regulate the infant's behavior and physiology and acts to insure physiological homeostasis and on the neuronal systems underlying behavior. Additionally, as the mother and infant are intimately together, they link their homeostatic systems into even more optimal organization called symbiosis. Symbiosis describes the mutual benefits during close proximity to each other. Loss of these regulatory functions results in changes in function and stability demonstrated through changes in the infant's and/or mother's behavior.

The Sensory Bioecology of the Newborn

During pregnancy, fetuses are developing in the ecological niche of the mother's body, and their sensory systems are primed for experience-dependent learning afforded by the mother's voice, body sounds, movement, day/night cycling, and other physiological exchanges. Sensory developmental preparation of the fetus results in physiological exchange in the newborn that is both familiar to and dependent on the mother's physical closeness. The infant born prior to term typically is separated from the familiarity of the mother's body yet is sensitive and responsive to the sensory environment of the NICU, even though they may not have sensory systems that are as developmentally mature.

Sensory systems do not develop in isolation, but are integrated with other sensory systems. Lickliter (Lickliter, 2011) in his studies of sensory development in avian and human infants proposed that infants utilize information derived from all sensory systems and then use this sensory information to increase the likelihood that events in their environmental niche can be detected, identified, and responded to. Infants, even at a young age, are able to integrate these multisensory inputs in order to make sense of their world, impacting how their brains detect, integrate, and use sensory information. He further describes how infants use amodal information that is not specific to a particular sensory modality but can be detected and used redundantly across multiple senses. These amodal characteristics are evident in most sensory experiences and include rhythm, tempo, synchrony, and prosody. Infants thus use redundancy across sensory systems to further understand their sensory environment.

Bahrick and Lickliter (Bahrick & Lickliter, 2014) proposed that intersensory redundancy is essential during infant development to describe how selective

attention is allocated to properties of objects and events. The redundancy hypothesis further describes how the detection of information not specific to any one sense guides selective attention. In this way, infants learn to selectively attend to a vast array of environmental stimulation and multimodal input. The fetus receives multimodal input in utero appropriate to their sensory developmental phase. The infant in the NICU may not receive sensory input appropriate for their developmental stage and in contrast may be either bombarded with unisensory input or multisensory input that is not multimodal or salient, but is a part of their bioecological niche. Additionally, the delivery of the stimulation that preterm infants may experience in the NICU may reduce the amount or availability of intersensory redundancy and thus have repercussions for early sensory integration (Lickliter, 2011). Regardless of the environment in which the infant develops, they are sensitive to and dependent on the salience of the intersensory redundancy and amodal features of the input. As neuronal plasticity is significant in early development, sensory experiences during early development may leave lasting functional and structural brain changes that can influence long-term intersensory interactions.

The bioecology of the NICU lays the groundwork for understanding appropriate and expected sensory experiences within the infant's developmental niche. The experiences are best integrated by interactions afforded by both the physical and cultural and the proximal and relationship environment in which they grow and develop. Thus, the bioecology of the infant within an NICU setting must provide opportunities for the infant to attend to a sensory environment that has both redundancy across sensory modalities and also amodal aspects to their presentation. This means that the infant can benefit best from an environment that has not only auditory, but optimally has visual, kinesthetic, and tactile modalities. Additionally, the infant should be provided an auditory environment that has rhythm, prosody, and tempo, typical during verbal exchanges. Multisensory inputs should also be presented when the infant is able (from an arousal perspective) to manage all of these modalities at the same time without state or physiological decompensation. The optimal provision of sensory redundancy and amodal characteristics is when the mother is holding, touching, moving, talking, and looking at the baby so that the baby can experience redundancy across sensory modalities and experience the feeling of having a "conversation."

The Social Bioecology of the Infant

Proximal interactions between parent and their infant are widely acknowledged to play a central role in influencing a wide array of developmental outcomes. Social competence and emotional regulation emerge from early relationships and provide significant foundational elements for optimal development. Early relationships are enhanced by interactions that are bidirectional between the parent and child and are characterized by verbal and nonverbal communicative and emotional behaviors (such as postures, facial displays, vocalizations, and eye contact). They have the

quality of coordination between the members of the dyad, and they share modalities during exchanges (Leclere et al., 2014). Thus, proximal environments such as those that support early interactions and positive relationships between mothers and their infants result in a supportive bioecology for the newborn and, in turn, optimize development.

Synchronous interactions between the mother and their infant provide the most important foundation for early relationship development. Synchrony occurs when the mother's and the child's responses and emotional capacity to respond to each other are maximized. It is a matching of behavior, emotional states, and biological rhythms that forms a single relational unit (Feldman, 2016; Leclere et al., 2014). Synchrony involves mutuality in regulation, reciprocal, flexible exchanges, rhythmicity in interactions, shared behavioral states and affect, and maintained engagement. Interaction synchrony addresses the matching of behavior, affective states, and biological rhythms between the members of the dyad to form a single relational unit. The familiarity of the partner's biobehavioral interaction and rhythms is exquisitely timed for highly aroused as well as comforting moments of interpersonal exchange (Feldman, 2015, 2016; Feldman & Eidelman, 2007; Leclere et al., 2014) which results from consistent and predictable caregiving.

Better mother child synchrony is associated with more positive cognitive and behavioral outcomes. Among preterm infants, opportunities for this shared synchrony are often limited, as studies have shown lower coherence during interactions, less mother and infant responsivity, and shorter episodes of gaze synchrony (Censullo, Lester, & Hoffman, 1985; Karger, 1979; Lester, Hoffman, & Brazelton, 1985; Lester et al., 2011). Main causes for the disruption in parent-infant synchrony among prematurely born infants relate to the baby's difficulties with physiological regulation and scant attention availability.

Imbedded in synchronous interactions is emotional exchange between mother and baby. The integration of vocal, verbal, and facial emotional information in a given situation provides the infant a context for emotional exchange (Bruck, Kreifelts, & Wildgruber, 2011). Processing of emotional exchanges associated with the perception of auditory and visual emotional signals includes extraction and integration of auditory and visual information into a single perception in the brain. Nonverbal vocal emotional signals such as the amodal components of sensory inputs are closely intertwined with verbal affective cues such as expressive words. In order to lay a foundation for social and emotional understanding and expressiveness during synchronous interactions, the infant needs both the verbal and the visual and the redundant and amodal characteristics inherent in emotional exchanges with a caregiver (Bruck et al., 2011).

Human mothers typically engage in complex, emotion-laden synchronous face-to-face exchanges with their newborns which include both gaze and physical contact (Brazelton, Tronick, Adamson, Als, & Wise, 1975; Cohn & Tronick, 1989; Lester et al., 1985; Tronick, 1989). These complex interactions imply that there is a motivation on the part of both members of the dyad to engage in social exchanges. Behaviors help caregivers understand the nature of what the infant needs (Simpson, Murray, Paukner, & Ferrari, 2014). Mothers are typically sensitive to the infant's

alertness and initiate engagements with social expressiveness and imitation of the infant's facial expressions. Current research attributes these behavioral interactions to a shared neural basis of empathy that highlights the value of neonatal imitation and shared emotional exchange as a behavioral measure of infant perception and action underlying early attachment behavior (Braadbaart, de Grauw, Perrett, Waiter, & Williams, 2014; Gonzalez-Liencres, Shamay-Tsoory, & Brune, 2013; Simpson et al., 2014).

The Distal and Proximal Bioecology of the NICU

The Distal Bioecology of the Infant in the NICU

Neonates in the NICU, by necessity, experience a bioecosystem with a history of revolving around the needs of medical and nursing staff in order to provide efficient and timely interventions (Philbin, Lickliter, & Graven, 2000). In the 1970s, there was an emphasis on reducing ambient sound in the NICU, largely because loud sound measured in the NICU was attributable to possible physiological changes and infant hearing loss and found to be common in preterm infants (Long, Lucey, & Phillips, 1980; Philbin et al., 2000). Early recognition of the impact of the sound environment of the NICU led to a series of recommendations and criteria for ambient sound reduction (Gray & Philbin, 2000; American Academy of Pediatrics, 1976).

Until recently, careful study of the benefits of sound reduction has reportedly not been well designed and carried out (Almadhoob & Ohlsson, 2015; Lasky & Williams, 2009). There has been a resurgence in the recognition of the impact of sound on the behavioral and state organization as well as neurodevelopmental outcomes of babies in NICUs (e.g., Kuhn et al., 2013; Morris, Philbin, & Bose, 2000) leading to acoustical and architectural design recommendations for NICU environments. Numerous attempts to modify the NICU environment and caregiving practices to be less invasive have been advocated by organizations such as the American Academy of Pediatrics, the Gravens NICU Design Consensus Panel recommendations, and the NIDCAP Federation International (White, Smith, Shepley,, & Committee to Establish Recommended Standards for Newborn, 2013).

The Proximal Bioecology of the Infant in the NICU

In the last decades, there has been an emphasis on not only reducing the distal sound environment of the NICU but also supplementing the infant's sensory proximal environment with music, mother's heartbeat sounds, and mother's recorded voice. These studies have focused primarily on the physiological responsiveness of the infant, both during painful procedures and during routine care, with purported benefits such as weight gain, enhancement of physiologic parameters, and shorter hospital stays.

Provision of Music in the Infant's Proximal Environment

Research on music therapy in the NICU has been initiated by a number of scientists in the past few decades. A review in 2013 (Allen, 2013) found music therapy, as an emerging intervention in the NICU, to lack consistency in research methodology and findings of reduction of hypoxia during stressful events. Allen's review of the then current literature indicated that additional research would be necessary before utilizing music as an intervention for sick preterm infants. It is noteworthy that the provision of music to infants was at a decibel level that was higher than the recommended standards for sound exposure in an NICU.

More recently, several studies have emerged that have used recorded music to focus less on physiological responses of the infant, and more on support infant arousal and neurodevelopment, in hopes of supporting the attachment relationship between mothers and their infants. Shoemark and associates (Dearn & Shoemark, 2014; Shoemark, Hanson-Abromeit, & Stewart, 2015) recognized that infants may be exposed to an unpredictable auditory background as well as the need for individualized approaches and parent presence in providing music to infants. Their research design included the playing of recorded lullabies with the parent present compared with when the parent was not present. However, the results showed no discernable impact of the mother's presence compared to when she was not present. Current contributions by Shoemark emphasize the music therapists' partnership with parents as they support the parents with "containment and soothing, enticement into interplay…," emphasizing that the work is essential to support the parent's interaction with their infant (Shoemark, Chap. 12, this volume).

Other research that included the exposure of infants to recorded lullabies and maternal voice have indicated that neither cortisol concentrations nor activity/rest patterns were influenced by music interventions (Dorn et al., 2014). More recently, Loewy and colleagues published a study of the effects of live music therapy on vital signs, feeding, and sleep in premature infants (Loewy et al., 2016) in a randomized sequence design. Their approach was to provide parent-preferred lullabies, sung live by the music therapist over a 2-week period. Their intent was to enhance bonding and decrease stress parents find with NICU infant care. In addition to short-term heart rate, sucking rhythm, and sleep pattern changes, they found decreased parental stress perception.

The provision of recorded music in the proximal environment of the infant in the NICU does not appear to have yielded consistent beneficial outcomes either from a physiologic or a behavioral perspective. The recordings may have not been individualized to the availability of the infant and not provided by a familiar caregiver. Although there was a beginning shift to having parents present in the NICU to observe the administration of "music therapy," even if the therapists used parent-preferred lullabies, parents have largely been excluded from singing the live lullabies themselves. The most recent study emphasized the provision of live music with some enticing findings of better physiologic organization in the infants and lowered perceptions of parental stress. More studies of live music presentations are necessary and hopefully will include the provision of music by familiar parents and caregivers.

Provision of Recorded Mother's Voice and Heartbeat in the Infant's Proximal Environment

Continuity between fetal and newborn exposure to the mother's voice indicates that the fetus is not only able to detect the mother's voice but also responds after birth to familiar verbalizations and narratives that the mother had provided during pregnancy. Moon has published a comprehensive review auditory development in the fetus and newborn (Moon, 2011). The continuity of auditory experiences from fetal to infancy lays the groundwork for attachment, language, and cognition. However, infants who are born early or spend time in the NICU environment are not afforded the benefit of continuity of their mother's auditory interactions. Understanding the benefits of maternal voice and heartbeat sounds on the developing fetus, studies have emerged to augment the auditory environment with recorded maternal heartbeats and voice for the preterm infant.

Krueger (Krueger, 2010) reviewed studies conducted over the years of 1972 to 2007 of exposure to maternal voice and found little research that addressed the preterm infant's loss of maternal voice continuity. She found that maternal voice recordings in those studies presented recordings above the recommendations for sound levels in an NICU. Additionally, the findings did not indicate significant beneficial outcomes on infant responsiveness. Her study emphasized the need for more research, particularly in the area of developmental outcomes that are a result of interventions that encourage parents to interact with their preterm infants.

More recent studies of maternal recorded voice and heartbeat effects on preterm infants sucking have noted that exposure to pitch modulation of the mother's voice yielded an increase in sucking (Butler, O'Sullivan, Shah, & Berthier, 2014). Other studies of maternal voice provided through bone conduction showed autonomic changes, visual attention performance, and general movements at 3 months, but not at 6 months of corrected age (Picciolini et al., 2014). Others have used similar administration of mother's voice and heartbeat sounds and have concluded that there is evidence for experience-dependent plasticity in preterm infants' auditory cortex (Webb, Heller, Benson, & Lahav, 2015), comparing their results with those found in term newborns' language-related cortical regions. In response to Webb et al., El-Dib and Glass (El-Dib & Glass, 2015) raise the question of whether brain acceleration in one area due to repetitive recordings is, in the long term, beneficial to the infant's outcome. These comments add to the cumulative calls for additional research on not only the appropriateness of recorded maternal voice and heartbeat but also on the potential long-term benefits for the development of the infant.

These studies raise important questions about the impact of recorded maternal voice and heartbeat on the experience-dependent newborn brain but may lead to understanding the effect of the mother's voice and heartbeat on infant short- and long-term outcomes. Currently the literature is sparce and limited in comprehensive longitudinal studies of infant developmental outcomes.

Recorded maternal voice and heartbeat has also been used to help reduce stress during the invasive procedures experienced in their proximal environments.

Although the literature is limited, there are a few studies indicating that infant exposure to recordings of maternal voice during adverse interventions such as arterial blood stick showed reduced pain-related behavior (Azarmnejad, Sarhangi, Javadi, & Rejeh, 2015). More recently Morelius and colleagues (Morelius, He, & Shorey, 2016) in their review of salivary cortisol reactivity in preterm infants during routine NICU care discussed "pleasant interventions" which included music, acoustic stimulation, maternal voice, and skin-to-skin care. They concluded that the literature on cortisol reactivity was inconsistent and needed further study for a variety of interventions including those defined as pleasant and which included music and mother's voice and heartbeat.

Other interventions for painful procedures that provide multisensory intervention include the provision of spoken vocalization. Initially Bellieni et al. and then Gitto and colleagues (Bellieni et al., 2007; Gitto et al., 2012) referred to non-pharmacological treatments such as "sensorial saturation" which included touch and olfactory and human auditory input during heel lancing. Bellieni found no difference in pain responses between mothers and nurses when sensorial saturation was provided. Gitto included parent's presence during the procedure, but parents themselves were not active in providing multisensorial input or vocalization. Both Bellieni and Gitto concluded that sensorial saturation was an effective non-pharmacological alternative treatment to relieve pain in neonates in the NICU.

Provision of Human Voice in Proximal Interaction in the NICU

The optimal proximal bioecology of the fetus is the uterine environment. Infants born early are typically devoid of the continuity of the consistent, predictable, orchestrated sensory experiences that were to be experience expected and are instead dependent on the NICU environment to provide coordinated sensory input. In contrast to the previously reviewed studies of the bioecological environment of infants in the NICU provided by recorded music and mother's voice and heartbeat, there are few studies that examine the benefits and/or difficulties of human live verbal exchanges between the mother and her infant in the NICU. One exception is the study by Filippa (Filippa, Devouche, Arioni, Imberty, & Gratier, 2013) and colleagues where the infant's mother was supported to speak and sing directly to her incubator-bedded infant. Significantly greater oxygen saturation and heart rate and fewer negative critical events resulted, and the infants came to alertness as if to interact with their mothers.

Other approaches that incorporate mothers and primary caregivers in verbalization with their infants are multimodal and multisensory in nature. White-Traut and colleagues (White-Traut et al., 2013) supported mothers to provide twice-daily auditory, tactile visual, and vestibular/rocking stimulation to their infants while in the NICU and as they transitioned home. The social interaction patterns of the experimental infants and mothers showed significant increases in responsiveness at 6 weeks corrected age.

Similarly, Welch and colleagues (Welch et al., 2012; Welch et al., 2014) supported mothers of preterm-born infants to engage in maternally and infant-mediated multisensory experiences by utilizing skin-to-skin opportunities, repeated "calming cycles," and speaking with their baby in their original language with emotion-laden content. Babies had significant optimal brain and behavior changes, and mothers had less anxiety and symptoms of depression.

Evidence points to the responsiveness of newborn preterm infants to proximal human voice interactions. Neurobehavioral assessments such as the Brazelton Newborn Behavioral Assessment Scale, the NICU Neonatal Network Scale, and the Assessment of Preterm Infant Behavior (Als, Butler, Kosta, & McAnulty, 2005; Als, Tronick, Lester, & Brazelton, 1977; Lester, Andreozzi-Fontaine, Tronick, & Bigsby, 2014) all support the baby to come to an alert state and respond effectively to a human face and voice. The responsivity of the infant can be optimized in a microsystem that allows for them to hear and see the examiner's face and voice and to make efforts to locate and interact with the examiner (Als, 1998).

Infants are exposed to a variety of distal and proximal sound environments that may have an impact on later receptive and expressive communication. Some of these environmental aspects are related to their exposure to live verbal exchanges in the NICU. Caskey and her group examined exposure to words and conversations during NICU stays for preterm infants (Caskey, Stephens, Tucker, & Vohr, 2011). Their remarkable finding that preterm infants make vocalizations as early as 32 weeks post-conceptional age and increase vocalizations over time contributes to our understanding of the bioecology of the infant in the NICU. They found that adult language was but a fraction of the sound that the infants were exposed to during their NICU stay and that parental verbal communication, especially during feeding at 36 weeks, predicted increases in infant vocalization. Additionally, their subsequent findings (Caskey, Stephens, Tucker, & Vohr, 2014) associated parent talk with their infants with higher 7- and 18-month language and cognitive scores on the Bayley III. These findings highlight the necessity of parental presence in proximal interactions with their preterm infants while in the NICU and beyond.

Skin-to-skin contact (SSC) has a growing research base in support of early physiological and neurobehavioral organization for prematurely born infants in the NICU, leading to the conclusion that provision of supports for STS care is a neurophysiologic imperative for both the mothers and their infants (Browne, 2004). In one unique study, mothers who engaged in singing to their preterm infant during STS care had reductions in anxiety and more physiologic stability in their infants (Arnon et al., 2014).

During STS care, the proximal environment for infants is their mother's or father's body. Their body provides the continuity of familiar, consistent, and predictable physiologic, vocal, and movement multisensory input that was initiated in utero. Infants in STS care are exposed to the human sound of the mother's heartbeat, body sounds, and vocalization, and the mother is additionally provided with coregulatory processes including vocal exchanges with the infant. These multisensory inputs are the best example of the developmental niche—the bioecological proximal interactions—that are experience expectant and that set the stage for experience-dependent brain organization. Furthermore, they provide redundant learning across

all sensory inputs—the sound of the mother's voice, her body movement and breathing, her familiar odor, and the physiologic organization provided by "hidden regulators." The amodal properties imbedded in these organized and intimate multisensory inputs provide the infant with an array of experiences that support their alertness and attention, their orientation to salient elements of their mother's location, and emotional detection and exchange. These building blocks are essential for social and emotional, language, and cognitive development (Feldman, Rosenthal, & Eidelman, 2014).

The Bioecology of NICU Design

With the recent advent of single family rooms within NICUs, where infants are cared for in separate rooms rather than one or two large multibed rooms or "pods," the bioecology of the newborn has evolved from the more historic infant grouping to individual or family unit design (White, 2003). Although there are data available on sound reduction in single family rooms as opposed to multibed units which were traditionally noisy (Philbin & Gray, 2002), research into the benefits of the single family room on infant developmental outcomes are emerging. Conflicting outcomes in the few current studies may be related to lack of sound input, isolation from sound experiences, or lack of opportunities for parents (White, 2003; Jobe, 2014; Lester et al., 2014; Pineda et al., 2014; Pineda et al., 2012; Rand & Lahav, 2014) to be interactive with their infant. Without opportunities for consistent interactions between infants and their mothers and other consistent caregivers, it appears that little vocal interaction and intimate exchanges are possible and could potentially have detrimental effects on infant development. Implications for assuring that parents are supported to be with their infants as primary caregivers and not "visitors" are apparent.

Initiated in Europe, "couplet care" focuses on never separating the preterm infant from his or her parents throughout the entire hospitalization (Ortenstrand et al., 2010; Westrup, 2015) and includes significant time for the parents to engage in skin-to-skin experiences. These experiences result in more optimal medical and developmental outcomes for the preterm-born infant. Thus, the infant is exposed to ongoing, consistent, familiar, and predictable verbal and other multisensory communication with parents.

Summary and Conclusions

Historically, the NICU has attended to the medical and caregiving needs of the preterm-born infant that included support for technology and personnel. Along with lifesaving interventions were an ambient environment that was technology based and largely excluded parent participation in their infant's care. More recent

recognition of the impact of the environment on the infant's organization and the benefits of parental care has provided an evolution in NICU caregiving and environmental design.

Understanding that the environment in which the infant grows impacts their experience-dependent brain organization and realizing that the NICU environment is not conducive to helping the infant transition from the "expected" environment of parental interactions and culture, professionals have developed strategies thought to enhance the infant's organization and neurodevelopment. Some of these strategies have included the provision of music in the form of lullabies, the mother's recorded voice and heartbeat, and, more recently, live singing of lullabies. As with the introduction of any new technology and/or innovative intervention for immature infants, questions arise as to the reproducibility of positive physiologic findings. Other questions include whether physiologic changes are the desired or appropriate measures to be investigated and if there are benefits to short and/or long term outcomes.

The fetus is already familiar with his mother's voice and body sounds and is expecting continuity when born into his human ecological niche. The mother's body provides regulation of her baby's physiology, arousal, and behavior, many of which are hidden to observation, yet are essential for survival. Unless there are significant opportunities for mother/infant closeness, an infant who spends time in the NICU may not benefit from these hidden regulators and alternatively is regulated by technology.

The human infant is dependent on experience within his or her proximal environment, largely through interaction with his or her parents and primary care providers. The sensory inputs that the infant is expecting are across systems, in fact, redundant and amodal so that the infant experiences the richness of the interactions with his mother. The best example of redundant, amodal sensory integration is provided by the proximal interaction when hearing the mother's voice, perceiving the emotionality of the interaction, seeing her face, smelling her particular odor, and moving in concert with her body such as when the dyad engage in skin-to-skin care. Efforts to reproduce these interactive components with technology cannot match the opportunities that infants are expecting of their developmental niche.

Synchronous interactions between the infant and his or her parents or consistent caregivers are now thought to lay a foundation for social and emotional development, which in turn results in more optimal cognitive, motor, and speech outcomes. Recorded administration of music or mother's voice and heartbeat represents a "one-way street," where the infant does not have a chance to reciprocally and synchronously develop social or emotional exchange, nor do they elicit emotional exchange between the members of the dyad. Further, parents often perceive that technology is an obstacle to interacting freely with their infant and may present unintended and ethically laden consequences (Lantz & Ottosson, 2013; van Manen, 2015).

Efforts by professionals to provide aspects of the mother's familiar voice, heartbeat, and preferred music reflect that the infant many times does not have parents

available to provide their personal sensory experiences. Might NICUs, hospitals, and indeed the social and economic fabric of our countries work hard to remove obstacles and promote families to be together during this critical developmental phase? Approaches in support of parental participation in the care of their infants where families are encouraged to be together and to sing, laugh, play, hold, and interact with their infants should become the optimal bioecology for developing infants. What is needed is NICU design that encourages family presence 24 h a day, 7 days a week; a culture change that incorporates strategies for integrating families into the caregiving fabric of the NICU; and abolishment of the viewing of families as "visitors." Strategies such as these will go far in assuring that the new bioecology of both distal and proximal environments of the preterm newborn will encourage synchronous verbal, physical, and emotional interactions and optimize infant neurodevelopmental outcomes.

Key Messages

- Developmental science has provided a foundation for understanding the need for appropriately timed and redundant intersensory experiences in order to optimize neurodevelopmental outcomes.
- The optimal bioecological niche of the infant in the NICU is the mother's body, voice, and movement where sensory familiarity, rhythmicity, and synchrony contribute not only to the emerging attachment relationship but also to later cognitive, neurophysiological, and socioemotional development.
- To enhance the bioecological niche of the infant in the NICU, obstacles should be removed, and opportunities should be promoted for families, and, in particular, mothers, to interact with their infants in intimate physical and vocal exchanges as frequently as possible.

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