The department is a part of a large hospital complex and is situated on the seventh floor, accessed from the main communication corridor. There are two entrances to the department. A reception area and a large room where parents and relatives can stay and meet is connected to the "public" entrance. This is a "home-like" environment with a kitchen and comfortable furniture. The other entrance leads to the outpatient clinic and home care facilities. The department consists of several different parts and is organized following the child's process to leave the hospital to go home. The sickest infants are in the most interior and remote part of the NICU. The step-down unit with single rooms for the new family is situated closest to the entrance. Couplet care, where both the child and mother need hospital care, is provided at both Level III and Level II.

The NICU space is organized into four units with three patients each. Each patient has a private room that is open at one end for joint monitoring. A small room for parents with toilet and shower is connected to each patient room. In this way, no parent needs to be separated from his or her child. Mothers' beds are brought bedside to the incubator and care for the child is given skin to skin. In conjunction with the NICU facility is a nutritional lab and a pharmacy. Space is also available for private counseling of parents, education, and meditation.

The new design of the neonatal unit at Karolinska Huddinge is important to meet the needs of the family while at the same time maintaining the highest quality care, patient safety, and a good working environment. The families do not have to change department or staff when the infant's health status improves. When the child is better, there are step-down rooms on the same premises. Home healthcare also has its base within the new department. A vision of family-centered care with a coherent chain from intensive care to residential care at home has characterized the work.

5.3.3 *Staff needs*

5.3.3.1 Staff stress

Researchers have found that high stress levels and the challenges of caring for critically ill children and their families has an impact on job satisfaction, which in turn may influence retention (Bratt et al., 2000). While few studies focus specifically on pediatric critical care, multiple studies address the impact of stress on hospital staff and the resulting burn-out syndrome (e.g. Poncet et al., 2007). ICU physicians and nurses are reported to have more stressful jobs than the standard working population (Goodfellow et al., 1997). Self-perception of stress levels may be at variance with actual stress levels, however, as suggested by the following study.

Fischer et al. (2000) obtained cortisol samples of pediatric ICU (NICU and PICU) and intermediate care physicians and nurses to determine endocrine stress reactivity (see Figure 5.19). To control for confounding variables, data were gathered via questionnaires on experience, objective stress, workload, and emotional attitudes toward work. Stress levels among NICU and PICU physicians and nurses were significantly higher overall. Mean cortisol levels were lower in more experienced individuals, but only in individuals with more than eight years of experience, size, and frequency of reactions. Interestingly, a high proportion of individuals experienced endocrine reactions

Figure 5.12: *Hospital for Sick Children Same Day Admit Unit, Toronto, Ontario, Canada (Architects: Zeidler Partnership Architects; Photo credit: Shai Gil)*

Figure 5.13: *Children's Hospital of Orange County PICU, Orange, CA (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.14: *Children's Hospital of Orange County PICU, Orange, CA (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.15: *Walt Disney Pavilion at Florida Hospital for Children PICU, Orlando, FL (Architects: Hunton Brady Architects; Photo credit: Ben Tanner)*

Figure 5.16: *Nationwide Children's Hospital PICU, Columbus, OH (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.17: *Nationwide Children's Hospital PICU, Columbus, OH (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.18: *Renown Children's Hospital PICU, Reno, NV*
(Architects: HMC Architects with interior design by Wilkoff Design Studio, LLC;
Photo credit: HMC Architects with interior design by Wilkoff Design Studio, LLC)

without conscious awareness of stress. Fischer et al. use repressed anxiety theory to explain this dissonance. The theory suggests that while fear can be hidden from the self, the biological representation cannot be controlled. As might be expected, the frequency of responses of both nurses and physicians was higher in less experienced staff. Figure 5.19 describes the activities evoking endocrine reactions in nursing staff. Data regarding physicians are also summarized in the Fischer et al. article.

In another study of PICUs/NICUs versus standard inpatient settings, Oehler and Davidson (1992), using the Maslach Burnout Inventory, found higher burn-out in critical care settings.

In addition to the stresses associated with work tasks, the physical environment has been found to contribute to stress. Morrison et al. (2003) measured noise levels in a PICU to determine whether they were correlated with nurse stress as measured by salivary amylase, questionnaires, and heart rate. Potential confounding variables were experience, coffee consumption, patient mortality risk, room assignment, and shift assignment. The most important environmental contributor to stress was sound. High sound levels were associated with tachycardia and evaluations of annoyance. Bailey and Timmons (2005) studied noise levels in the PICU and found that staff conversation was the most common source of noise.

5.3.3.2 Staff satisfaction

Although a few studies are available that discuss staff satisfaction as a result of operational protocols, surveys do not typically include environmental features. Ernst et al. (2004) studied

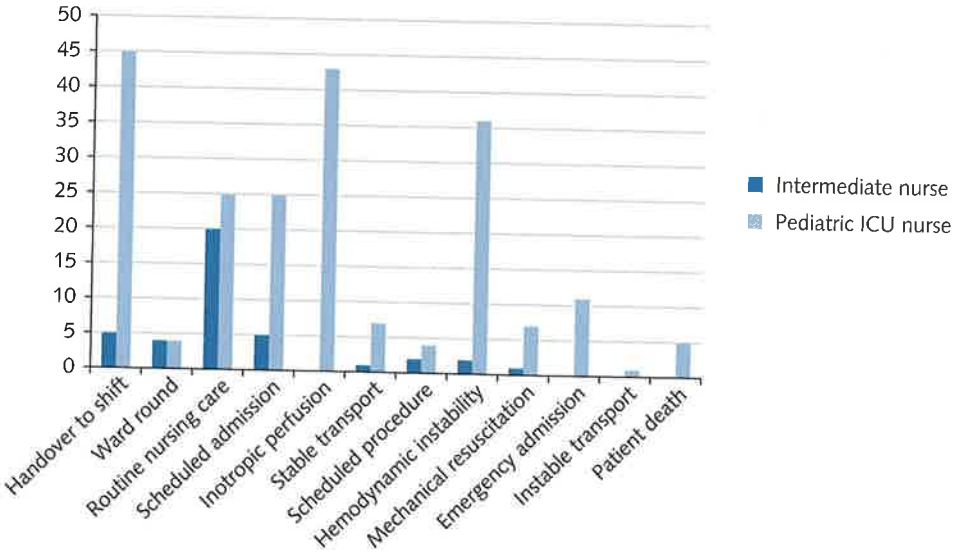

Figure 5.19: *Comparison of critical care and non-critical care cortisol events (Source: Derived from Fischer et al., 2000)*

nursing staff in a children's hospital, including three ICUs, and found that pay, sufficient time, confidence, and task assignment impacted satisfaction. The closest study I uncovered regarding satisfaction with the physical environment in inpatient units was by Tumulty et al. (1994), who found comfort to be a factor.

5.3.3.3 Examples of staff spaces in PICUs

Figures 5.20 to 5.31 are examples of staff spaces in PICUs in approximate chronological order. The location, design firm(s), and photo credit are provided. Staff spaces range from nurses' stations (centralized and decentralized) to lounges and nurse servers.

5.4 Research on needs of NICU patients, families and staff

5.4.1 Infant needs

One of the clear needs of an infant is a relationship with his or her parents. Morgan et al. (2011) found that maternal–neonate separation results in a 176 percent increase in autonomic activity and an 86 percent decrease in quiet sleep duration compared with the skin-to-skin contact.

Sleep is another significant need of infants. Sleep helps preterm newborns enhance clinical outcomes, achieve weight gain, improve oral feeding, and develop more substantive parent–infant relationships. Sleep is a key factor in the development of the brain. To protect sleep, Colombo and De Bon (2011) recommend reducing noise levels, creating periods of semi-darkness,

Figure 5.20: *Shands Hospital for Children at UF PICU, Gainesville, FL (Architects: Flad Architects; Photo credit: Courtesy of Flad Architects)*

Figure 5.21: *Naval Medical Center San Diego PICU, San Diego, CA (Architects: Ravatt Albrecht & Associates)*

Figure 5.22: *Metrohealth Medical Center PICU, Cleveland, OH (Architects: DeWolff Partnership Architects, Cleveland, OH/Rochester, NY; Photo credit: Rendered by DeWolff Partnership Architects)*

Figure 5.23: *Children's Hospital of Orange County PICU, Orange, CA (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.24: *Children's Hospital of Orange County PICU, Orange, CA (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.25: *American Family Children's Hospital PICU, Madison, WI (Architects: HDR; Photo credit: Ballogg Photography)*

Figure 5.26: *Gillette Children's Specialty Healthcare PICU, St. Paul, MN (Architects: BWBR Architects, Inc.; Photo credit: Mark Baumhover, BWBR)*

Figure 5.27: *Gillette Children's Specialty Healthcare PICU, St. Paul, MN (Architects: BWBR Architects, Inc.; Photo credit: Mark Baumhover, BWBR)*

Figure 5.28: *Mercy Children's Hospital PICU, Creve Coeur, MO (Architects: Christner Inc.; Photo credit: Sam Fentress)*

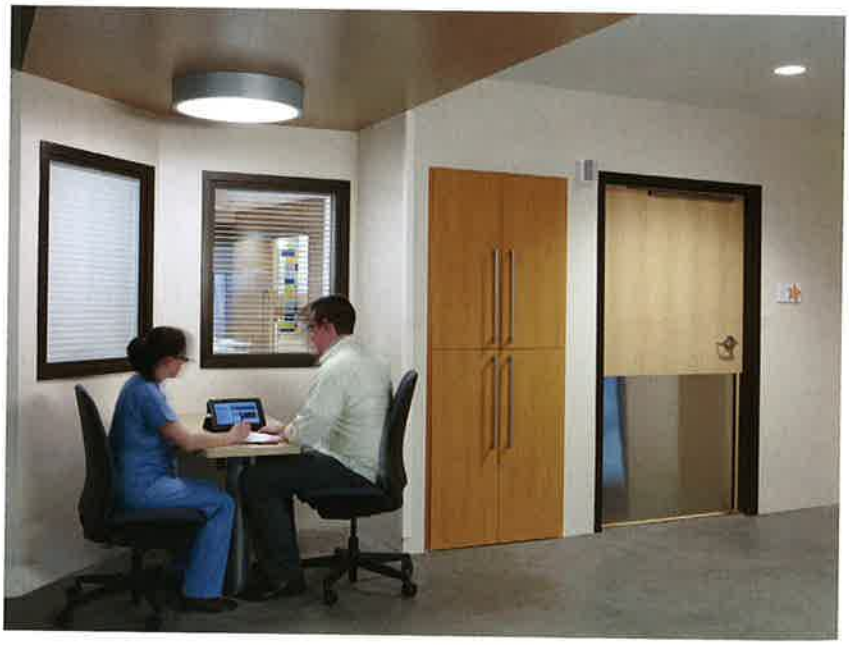

Figure 5.29: *Children's Hospitals and Clinics of Minnesota PICU, St. Paul, MN (Architects: HDR; Photo credit: Philip Prowse Photography)*

Figure 5.30: *Nationwide Children's Hospital PICU, Columbus, OH (Architects: FKP Architects; Photo credit: Courtesy of FKP Architects)*

Figure 5.31: *Phoenix Children's Hospital PICU, Phoenix, AZ (Architects: HKS; Photo credit: HKS, Inc.)*

and protecting infants' faces from direct light. The presence of parents helps the baby feel more protected and allows him or her to relax.

Yamile Jackson discusses the role of brain-oriented care and family-centered care in the NICU in her guest author essay.

Advancing brain-oriented care in the NICU: challenges and opportunities

Yamile C. Jackson, CEO, PhD, PE, PMP

Parents often describe the NICU as a roller-coaster, and that was in fact our own experience. The five months in the NICU when my son Zachary was born in 2001 at 28 weeks and weighing 906 grams substantially changed my personal and professional life. I made a promise to him that his pain and struggle to survive were not going to be in vain. Zachary's story is a painful one, traumatic enough to be the inspiration of the TNT movie *14:Hours*, but it has a happy ending. Sadly, I truly believe that in 2001 I experienced an environment that was more centered in the family than what many families experience now in some hospitals.

I truly believe that Zachary beat all the odds and is alive and healthy today in large part because the staff empowered me and taught me how to be effectively involved. I kanga-rooed Zachary for five to seven hours of the 10 to 12 hours I spent in the NICU. I had to leave because there was no place for me to stay longer than that. The staff taught me how to become his "developmental specialist" so that I could continue his care at home following discharge. My appreciation goes to each and every staff member in all NICUs around the world and my mission is to help you offer developmental care that is centered in the family.

The Institute for Family-Centered Care (IFCC) lists the core concepts that help parents as: Dignity and Respect, Information Sharing, Participation, and Collaboration (AHA, 2004). "Family Participation" has as many interpretations as the number of NICUs and PICUs in the US; however, in all of them, newborns and their families need each other from birth and for the rest of their lives.

Since there are no standards, procedures, or scorecards that help a family or the staff determine the level of "participation of families" in a hospital, it is easy to understand why virtually all professionals give a positive response when asked if they practice family-centered care (FCC). Some even say they do so because they are open 24/7 or because they have single family rooms.

FCC is imperative in the NICU and PICU more so than in any other unit of the hospital because everything we do (or don't do) affects brain development and the lifetime of the baby, the family, and society at large. Working together with families will improve the babies' odds of enjoying as normal a life as possible.

It is not difficult to infer the level of family participation in an ICU: simply look around the unit. At any given time, what percentage of parents is present? For the time parents are present, what percentage of time do they spend holding the baby in skin to skin,

or if they don't qualify for kangaroo care, they are by the bedside bonding, touching, talking, and reassuring the baby that he or she is not alone, abandoned, or in solitary confinement? Are parents confident about their ability to provide the best possible developmental care for their baby at the NICU and after discharge? Are fathers involved and encouraged to kangaroo their babies? Do parents feel hopeless and impotent or do they know how much they can help their babies and what kangaroo care can do so that they need to be present? Will they choose the same hospital if they have another baby? How have those numbers changed from last year/month?

> Family centered care is a philosophy of care that embraces a partnership between staff and families. Unrestricted parental presence in the NICU, parental involvement in infant caregiving, and open communication with parents are basic tenets of family centered care. By virtue of their continual presence and role in the NICU, nurses are in a unique position to support family centered care.
>
> (Griffin, 2006)

Don't stop after telling the parents the bad news – there is good news too.

Parents need and want to know how prematurity can affect their baby's life and what they can do to mitigate deficiencies and disabilities. Contrary to what I heard in the NICU in 2001 with Zachary, there is some evidence which suggests that apnea and bradycardia are not caused by the immaturity of the baby's system but by the poor environmental conditions we are providing in the NICU. Preemies do not "catch up" at 2.5 to 3 years old and many disabilities or deficiencies will not be known for years after discharge. Premature babies are not just tiny; they are at risk for a number of health concerns, including breathing difficulties, brain injury, eye disorder infection, bowel problems, and heart dysfunction. Some of these concerns are short term and others long term (Marlow, 2004).

One study found that at age 6, 22 percent of low birth weight children had at least one psychiatric disorder, with Attention Deficit Disorder and anxious disorders being the most common (Whitaker et al., 1997). More than half of babies who are born 10 weeks or more before their due date suffer brain damage (Volpe, 2000); and almost half of children who survive extremely preterm birth have neurologic and developmental disabilities (Peart, 2008). A study from the United Kingdom suggests that extremely preterm babies who survive to leave the hospital have about a 50:50 chance of being free of disability at age 2.5 (Wood et al., 2000).

However, the good news is that the evidence is bright when it comes to brain development and parental intervention. The baby's sleep is a basic physiological need. Sleep is very important for recovery, growth, brain development, learning, and memory. Moreover, disturbances in sleep can cause exhaustion, damage to the developing body, dysfunction of the immune system resulting in susceptibility to infection, and it can also cause serious stress and agitation (Bertelle et al., 2007; Graven, 2006).

I have spent 11 years helping babies sleep under the extreme conditions of the ICU and applying engineering, technology, ergonomics, and parental intervention (or its simulation) to the prevention of deficiencies commonly attributed to prematurity. Our goal is that every child can sleep, be comfortable and comforted on the bed or while

being held so that the brain develops, she or he grows, experiences a safe and seamless inclusion into his or her family, and goes home enjoying the best possible quality of life for a lifetime.

There is evidence that babies sleep better in kangaroo care (Ludington-Hoe et al., 2006) and that cerebral oxygenation is improved during kangaroo care (Begum et al., 2008) and all the numerous benefits of kangaroo care for the baby. There is still the perception that kangaroo care (KC) is reserved for improving breast milk production or for underdeveloped countries that don't have access to equipment. Fortunately, it is recommended for babies in high-tech environments in NICUs in developed countries (Anderson et al., 2001), as it supports an infant's optimal adaptation to extra-uterine life, provides the optimal neurosensory environment for brain development, facilitates maternal–infant bonding and attachment, empowers the mother as primary caregiver, facilitates initiation of lactation and breast-feeding, and prepares for a successful discharge (Nyqvist et al., 2010).

Because preterm infants are susceptible to cerebral lesions due to immaturity, the effects of KC on cerebral hemodynamics ("blood movement") should be known. Cerebral oxygenation is an important parameter in cerebral hemodynamics (Begum et al., 2009).

It is my vision that parents and caregivers around the world support not only infant bonding and attachment to their parents, but also the child's sensory and brain development by minimizing the environmental stress of the neonatal and pediatric intensive care units.

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5.4.1.1 Developmental care

Developmentally appropriate care is care that is customized to meet the needs of an infant at his or her specific age of physical maturation. The Synactive Theory of Development is a conceptual framework that describes the capabilities of the fetus and newborn. According to this theory (Vandenberg, 2007, p. 83),

> The infant's ability to regulate and control behavior emerges through continued interaction with the environment and is expressed through five systems: autonomic/physiology, motor, state, attention/interaction and self-regulation. In the healthy full term newborn the five subsystems are mature, integrated, synchronized and managed smoothly. The less mature, healthy or sick preterm newborn may be unable or partially able to manage environmental inputs, demonstrating over-reactive responses and poor tolerance from even minimal input.

According to Vandenberg, if medical staff are unable to interpret an infant's sensitivity levels and adjust care protocols, the infant will experience stress responses and lack of control. This idea of adjusting the level of the challenge of the environment to meet the competence of the individual is an exact reflection of Powell Lawton's Environment Competence/Press Theory (1974) discussed in Chapter 4.

Haumont discusses the Neonatal Individualized Developmental Care Assessment Program (NIDCAP) in this context in her guest author essay.

Moving away from the traditional NICU toward the early developmental care NICU

Dominique Haumont, MD

Perinatal mortality in very low birth weight infants has dramatically decreased during the past decades. However, 15 to 25 percent of these infants will show neuro-developmental impairment later on. A recent meta-analysis showed that at school age

those children scored around 10 points lower on cognitive tests compared to matched controls.

The aim of implementing early developmental care (EDC), a new field in neonatology, is to create an intervention program designed to provide support for optimal neurobehavioral development during this highly vulnerable period of brain growth. The theoretical framework, which underlies the approach, is supported by research in different scientific fields, including neuroscience, psychology, medicine, and nursing. EDC utilizes a range of medical and nursing interventions that aim to decrease the stress of preterm neonates in NICUs. The Neonatal Individualized Developmental Care Assessment Program (NIDCAP) is an integrated form of developmental care and appears to be the most comprehensive, holistic and family centered. NIDCAP addresses many aspects of what the preterm infant is experiencing. Reading the preterm infant's behavior and responding to the baby's stress signals, respecting sleep organization, diminishing pain, providing appropriate light and sound environment, and restoring the child–parent relationship are some of the factors that have an impact on outcome and which are addressed intensively when implementing the sophisticated and complex NIDCAP approach.

Changing the traditional NICU toward an EDC-NICU includes, most importantly, training nursing and medical staff, investing in their quality, and keeping parents in proximity to the infants. Introduction of EDC involves investment of time, energy, and financial resources. Success will depend on strong commitment of the medical, nursing, and hospital directors.

Traditional NICUs are typically designed for the administration of intensive care in the same way as adult intensive care. The developing aspect and the extreme vulnerability of the preterm infant, the need of the parental presence, and the duration of the stay have been totally neglected. Moving toward an EDC-NICU will push caregivers to struggle for space and new conceptual architectural driving trends. Major changes to achieve a developmental/healing environment consists in increasing infant care space, natural and individual lighting, decreasing noise, reflection on family-centered care, staff needs, and single rooms with rooming-in facilities. Developmental care could prove to be an important recent step in improving outcomes in extremely preterm neonates.

5.4.1.2 Music and maternal sounds

Researchers have studied the impact of music on infants in NICUs (e.g. Arnon et al., 2006; Cassidy and Standley, 1986; Standley and Moore, 1995). Standley (2002) conducted a meta-analysis of the impact of music therapy for premature babies and found a significant effect, not mediated by the infant's gestational age or birth weight.

Burke (2000) found that vibrotactile music did not promote sleep but did show evidence of reducing agitation and stress during medical interventions. Burke et al. (1995) also found a positive effect of music on the impact of medical interventions. Similarly, Butt and Kisilevsky (2000) suggest that music may help with the recovery from pain.

Standley and Moore (1995) conducted a study on exposure to music over several days. On the first day, the researchers reported high oxygen saturation levels, which decrease over subsequent days. They also found that babies had significantly depressed oxygen levels when the music was turned off.

One of the primary functions of music has been to mask inappropriate noise (Stewart and Schneider, 2000) or serve as a distraction, and this is a possible application to the NICU environment.

Another technique that has been used in NICUs is the incorporation of prenatal maternal sounds (voice and heartbeat) in the experience of newborns. Panagiotidis and Lahav (2010) found an incubator audio system to be safe and feasible. Doheny et al. (2012) found that preterm infants had a decreased risk of cardiorespiratory events when exposed to maternal sound stimulation as opposed to normal hospital sounds. The effect was significant in infants greater than 33 weeks' gestation, which suggested to the researchers that there is a specific therapeutic timeframe in which the maternal sounds are most effective.

5.4.1.3 Impact of lighting

There is a considerable body of research on appropriate lighting for newborn and premature infants. Dr. Stanley Graven provides an excellent description in his 2004 article of the neuro-sensory visual development of the fetus and newborn (Graves, 2004). This information serves as background when considering the design of the physical environment surrounding NICU infants.

As mentioned previously, the issue of appropriate light levels and acoustics is directly related to development care, as preterm birth interrupts the inter-uterine development of sensory systems. Inappropriate light and sound stressors have been found to impact sleep-awake phasing, self-regulatory behaviors, and other stress-indicating behaviors (Peng et al., 2009). Researchers note that the lighting needs of NICU infants are directly related to the gestational age and health status of the infant.

An early study (Giunta and Rath, 1969) suggested that high light levels might positively impact infant outcomes. These researchers exposed uncovered babies to constant light levels (90-foot candles) and compared them to those clothed in a 10-foot candle environment. The researcher found lower bilirubin levels (high levels are associated with jaundice) in the population that was exposed to the light. The exposed children in this study were not evaluated regarding the impact of the light levels on the development of their visual system; however, subsequent studies suggest that the light exposure does not negatively impact the retinopathy of prematurity (DiBiasie, 2006).

One of the most commonly discussed issues in lighting in NICUs is the role of circadian rhythms. Mirmiran and Ariagno (2000) note that circadian rhythms develop during the fetal period in response to maternal entraining; the day-night fetal heart rate rhythm is synchronized with the heart rate, rest-activity, cortisol, body temperature, and melatonin of the mother. The presence of these rhythms in young preterm infants should be supported in the care of the premature infant, although this should be done with an awareness of the negative implications of over-stimulation. Intense variations in light levels, for example, would not be appropriate for low gestational-age infants. Brandon et al. (2002) found that cycled light had short-term advantages over long periods

of near-darkness. Those infants experiencing cycled light demonstrated greater weight gains. There were no statistical differences between ventilator days, auditory loss, length of stay, and retinopathy.

According to Frank et al. (1991), the most common lighting problem is strong overhead lighting, as is used in open-bay settings. Others have indicated the difficulty associated with lack of ability to reduce light levels or raise light levels when necessary for specific tests, a particular problem in an open-bay setting. For example, light levels may need to be reduced to very low levels to support equipment used in the assessment of pneumothorax (Beeram, 2013).

More detailed information on other research related to light in the NICU is provided in the guest essay by Yilin Song.

Lighting in the NICU

Yilin Song, M. Arch, PhD in Architecture candidate

Lighting is one of the most important environmental factors in NICU design. Lighting influences the outcomes of infants, the experience of families, and the behavior of healthcare professionals. However, the actual effect of lighting, especially of daylight, is a complicated topic and that needs significant exploration.

Infants and caregivers have different lighting needs. For babies, their needs may vary by gestational age and health condition. Babies sleep for most of the day before they are 1 year old (White, 2004). Meanwhile, considering their underdeveloped visual systems, the primary principle of lighting design in NICUs is to eliminate excessive direct light on infants, and to provide an appropriate sleeping environment (Bowen, 2009; White, 2006). From the perspective of caregivers, they observe patients day and night, detect infants' skin coloration, measure their heart and respiration rates, and write down or input electrical medical records near the bedside. While the dim lighting seems appropriate for the infants in the NICU, it is a quite difficult work environment for caregivers to maintain alertness and fulfill tasks and healthcare responsibilities (White, 2005). Staff require bright lighting to improve their work efficiency and effectiveness, and therefore ensure patient safety.

Both electric lighting and daylight have advantages and disadvantages. With good planning and control, electric lighting can provide the required lighting levels for any space at any time. However, people who stay in electric lighting environments for a long time may become disoriented; their circadian rhythms are disrupted, especially for nurses and staff who work night shifts (Stevens and Rea, 2001).

In contrast, daylight is a more natural and sustainable approach; the lighting levels change in response to time, dates, and weather. Both patients and caregivers can experience the diurnal cycle, which may have positive influences on their physical and spiritual conditions.

We all know that natural light benefits people's circadian rhythms. Figueiro et al. (2006) mentioned that babies "receive light/dark signal information through maternal time-of-day cues (e.g., hormones and activity)" before birth (p. S24). Mann et al. (1986) compared

day–night cycled light with continuous lights, while Brandon and colleagues (2002) studied the influence of near-darkness to cycled light on preterm infants. Both of their studies found significantly more weight gain in the group of infants in a day–night cycled light environment (Floyd, 2005). Other related research illustrates that infant patients with cycled lighting had fewer days on ventilators, improved motor coordination, and earlier initiation of oral feedings. Lower light levels in NICUs reduce infant respiratory instability; decrease their heart and respiratory rates and activity levels; and reduce time spent on mechanical ventilation and oxygen support (Bowen, 2009).

In addition to the biological need for natural light in human beings, views of nature are important. Previous studies offer evidence that providing views of nature may decrease staff stress and increase their satisfaction (Ulrich et al., 2008). In the Recommended Standards for Newborn ICU Design developed, the authors suggest having at least one source of daylight visible from the NICU room instead of requiring direct access to daylight. The reason behind it is the psychological benefit of windows to caregivers and patient families (White, 2006).

The main challenge of daylight is the difficulty of constantly maintaining and controlling the required levels of lighting. In the NICU the most critical issue is to prevent excess lighting exposure to infants. The design of the environment and medical protocols must avoid direct light into infants' eyes by shielding the incubator with a cover; lowering indirect lighting during the night, and permitting infants to sleep while maintaining staff work (Floyd, 2005; Bowen, 2009). We need to explore more effective ways during both the design process and the caring practices.

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5.4.1.4 Acoustics

The inappropriateness and possible negative impact on health outcomes of unnecessary noise on NICU children is clear. Excessive noise has been found to negatively impact the premature infant by increasing blood pressure, heart rate, and respiratory rate, and decreasing oxygen saturation (Bremmer et al., 2003). Noise levels have been found to be greater in Level III than in Level II NICUs (Levy et al., 2003).

A discussion of the acoustical needs for infants is informed by the literature survey provided by Stanley Graven (2000). The following 10 of his 16 conclusions are of particular interest to the acoustical design of neonatal environments:

1. The human fetus is sufficiently developed at 23 to 25 weeks for sound to produce physiologic effects.
2. The human fetus has the ability to discriminate voices and develop auditory memory regarding speech and music.
3. Prenatal exposure of the fetus to maternal speech may impact subsequent language development.
4. The sequence of the senses is thought to be touch, movement, chemosensory (e.g. olfactory), auditory, and then visual, regardless of whether the birth is premature.
5. Intense low-frequency sound *in utero* can damage hair cells of the cochlea.
6. The auditory system is sufficiently developed by 30 to 32 weeks to support auditory learning.
7. The *in utero* sound experience is impacted by the maternal tissues which attenuate frequencies >250 Hz.
8. Continuous sound >60 dB has been associated with hearing damage.
9. Noise >50 dB has been associated with sleep disturbance.
10. Preterm infants may be subject to learning problems later in life.

Researchers have noted that sound levels in ICUs frequently exceed recommended standards (e.g. Larson, 2010; Thomas and Uran, 2007; Vandenberg, 2007). Vandenberg (2007) recommends that sound levels should not exceed 50 dB and transient sounds should not exceed 70 dB. In a study of a NICU in Canada, Kent et al. (2002) noted that noise levels inside an incubator (61 dB) were higher than the levels outside (58 dB). The areas associated with staff activity occasionally measured 120 dB. Saunders (1995) found that covering the incubator was an effective way of reducing noise.

One of the expectations of the benefits of SFRs is their potential ability to control noise. Liu (2011) compared SFRs to open-bay units and found SFRs to be quieter except when high-frequency ventilation was used.

According to Frank et al. (1991), the biggest contributors to acoustical problems are large rooms, space limitations, overcrowding, and staff conversation. Issues with regard to staff conversation have also been identified by Bremmer et al. (2003). Slevin et al. (2000) identified the variety

of sources as shown in Figure 5.32. According to this study, reductions in light, noise, and activities have been associated with reduced diastolic blood pressure, arterial pressure, and infant movements – typically desirable outcomes (Slevin et al., 2000). In spite of efforts to reduce noise levels in NICUs, researchers have had difficulty achieving appropriate standards (Byers et al., 2006). One solution – the inclusion of foam in an incubator – decreased the noise level by an average of 3.27dB (Johnson, 2001).

Thear and Wittmann-Price (2006) measured the impact of a series of protocol and environmental modifications on noise levels including a noise indicator when sound levels exceeded 60 dBs, an hour of quiet three times a day, changes in nurse schedules, instructions to parents and memos to ancillary staff about the importance of noise control, and door replacement. Noise reductions were achieved and continued to be effective three, six, and twelve months later.

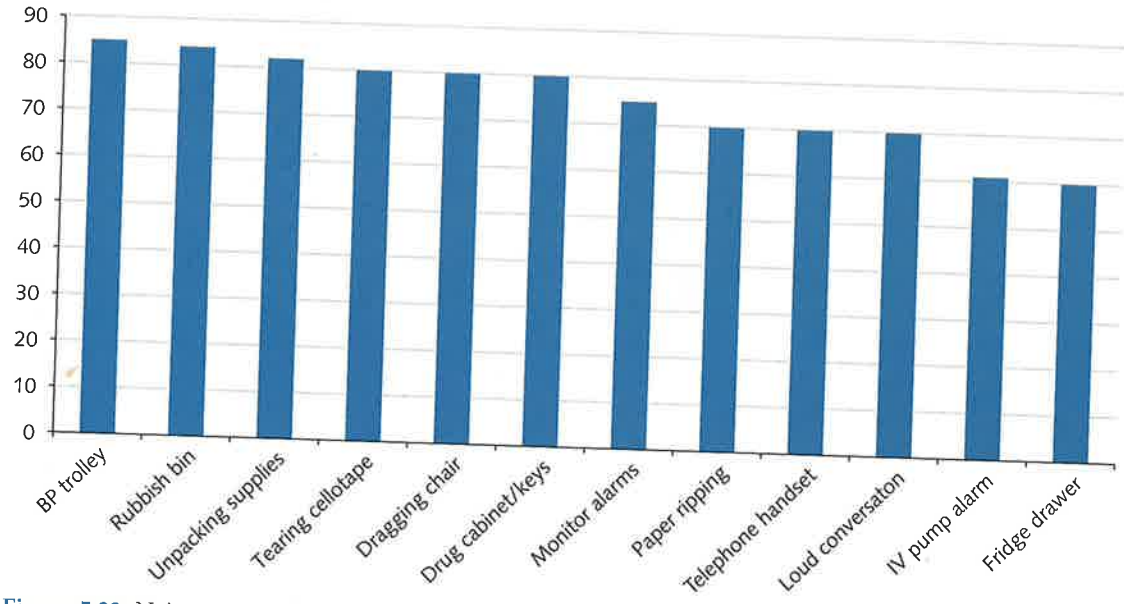

Figure 5.32: *Noise sources and dB levels in NICU (Source: Derived from Slevin et al., 2000)*

Gray and Philbin (2004) provide an in-depth summary of the effects of the NICU environment on the auditory attention and hearing of infants, noting the difficulties preterm infants face with regard to the challenges of a chaotic environment (as well as the difficulties faced by NICU adults). According to these researchers, the differences between the acoustical experience of a third-trimester fetus and a preterm baby are as follows:

- Fluid conducted versus air conducted.
- Mostly low frequencies versus all audible frequencies.
- Quiet to moderately loud versus loud to extremely loud.
- Narrow ranges of patterned signals with a moderately competing background versus a wide range of unpatterned signals competing with a loud background.

- Multiple repetitive patterns versus few or no patterns.
- Signals associated with circadian rhythms versus no circadian rhythms.

According to Gray and Philbin (2004, p. 257),

> We assume that an acoustic environment similar to that of the third trimester fetus would be most advantageous to the preterm infant's physiologic and behavioral stability as well as long-term outcome ... it seems prudent at least to eliminate the acoustic sources of stress or disorganization known to be associated with noise. Many developmental challenges associated with intensive care are very difficult to alleviate: pain, handling, separation from expected physiologic supports and regulation of the mother's body. However, the acoustic environment can be managed purposefully through design and construction of the physical space and equipment and by conscious action on the part of adults using the space.

One of the primary reasons for providing single family rooms is their potential for developmentally appropriate acoustical control. Philbin makes the important point that providing a single family room in and of itself does not mean that acoustical control has been achieved (see Philbin, guest essay).

Noise and single room design: correction/prevention and an interesting alternative

M. Kathleen Philbin, RN, PhD

The pendulum swings

NICU staff have worked in impossibly crowded, multiple-bed rooms for so many years that, once in view, the single infant/parent room became a force of its own. Room size became an institutional goal and bragging right. NICUs with plenty of space had it all. Others with limited space had single rooms at a price: no parent lounge, a staff lounge too small for the staff, meeting rooms on another floor, etc. Others with meager space had crowded cubicles for rooms, curtains for the fourth wall, noise, and unhappy parents and staff alike.

Hallway deflections

The single-room NICU is often arranged along a lengthy hallway with patient rooms on one side (for daylight) and staff spaces on the other. The hallway is in constant use. The staff of one, new, jaw-droppingly beautiful NICU say the noise is unbearable and worse than the old NICU. The hallway has standard hospital ceiling panels, a thin laminate floor, and spectacular walls – all of them reflective. It is absolutely straight and very long, with pockets on the side for staff work and an open Level II nursery just off one end. The noise affects everyone. A sound wave can travel the full length without interruption, deflect from the end wall, travel back, deflect from that end wall, and on and on. Waves moving at an angle are deflected into the hallway by every surface. The movement of a stool at a workstation measured 88 dBA about 5 feet from the source. Snapping shut the

clasp of a small plastic box was 98 dBA at one end of the hallway and 89 dBA at the other. Having recently spent a fortune, administration is not interested in mitigation.

Recruitment

Single rooms themselves can be noisy. This seems illogical for a large room with four walls, a door, and two people, even if all the surfaces are hard. Indeed, the room is very quiet when activities are quiet and few. However, the quietness and reflective surfaces can operate together to cause a moderately loud sound to be perceived as jarring and louder than indicated by a sound level meter. The perception of greater loudness is due to the contrast with the usual quietness and is a function of hearing called recruitment (Green, 1976, pp. 322–324). In this room normal activity becomes a constant, jarring noise.

Acoustical glare

Sound in some single rooms may be perceived as unpleasant, even if not loud. Leo Beranek writes, "If the sidewalls … or surfaces … are positioned to produce early sound reflections [as they would be in a small room with hard surfaces], the sound from them may take on a brittle, hard, or harsh quality, analogous to optical glare" (Beranek, 2004, p. 31).

Mitigation

Each of these problems can be mitigated by maximum surface absorption. The ceiling is a large plane where highly absorbent ceiling panels can reduce sound more than any other surface treatment. Some can absorb 100 percent of the sound reaching them, while hospital grade panels absorb about 50 percent. The cost difference between the two is small and the acoustic difference is dramatic.

Acoustic treatment of the floor is usually the second most effective and practical means of sound reduction. Some sheet flooring has multiple options for cushioning layers with some options able to prevent sound originating on the floor. This flooring has a durable surface, comes in many colors and patterns, resists staining, does not need waxing, cushions joints for long periods of standing, and *reduces* sound by 20 percent. Hospitals use such flooring routinely in operating rooms. Again, the difference when walking between this and standard laminate on cement is immediate and dramatic.

Jogs in a hallway lower sound levels by adding deflecting surfaces that interrupt long reverberation distances. Non-90-degree angles where planes intersect also interrupt reverberation by adding more deflections than 90-degree angles.

Beyond noise and quiet

Planning a new NICU is an opportunity to go beyond noise prevention and create a specific sound quality such as warmth, or definition/clarity, or intimacy, or listener envelopment (Beranek, 2004, pp. 31–32). Consultation to achieve a specific sound quality need not be expensive if work with the room acoustics specialist starts with initial planning.

The multiple-bed room: space and privacy

Multiple-bed rooms use space efficiently and have many advantages for nursing assignments and patient care. However, staff tend to oppose them out of concern for noise and for parent and staff privacy. Multiple-bed rooms can be as quiet as any other. Attractive individual (not assigned) parent spaces can be built near the unit. Substantial, movable

screens can provide visual privacy for family and staff. Speech privacy is also possible. "Speech privacy" means that one person, a specified distance from others in conversation, can hear voices and but not specific words. Designing for specific speech privacy requirements is a common function of acoustical engineering.

A single room also has speech privacy but speech and personal isolation as well. Most mothers in a single room would not use the call bell for something small but worrying; they would sit with their anxiety. In a multiple-bed room, by contrast, a nurse is likely to be nearby and available to "take a look." Above all, the advantage of a multiple-bed room is that parents can go home knowing their baby is with a nurse and not in a room alone.

The myths

The following, quite mistaken beliefs are strongly held by some involved in NICU design.

1. "Sound floats up, a characteristic that makes a very high ceiling a good means of sound attenuation."
2. "Sound in a three-wall room will be caught by a 2" lip on a 15" fur-down across the top of the absent "fourth" wall. All sound in the room goes up to that lip area and stays there, keeping it from going into the hall."
3. "Between-bed curtains are effective sound barriers."
4. A large piece of equipment in the middle of a room or a picture on a wall will "break up" sound and lower sound levels.

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5.4.1.5 Climate

Researchers have documented the thermal comfort needs of infants. As one example, Salihoğlu et al. (2011) recommend a temperature of 22 to 26 degrees Centigrade (71.6 to 78.8 degrees Fahrenheit) and relative humidity of 30 to 60 percent. Thomas et al. (2010) found that NICU climate conditions vary by season, a situation that should be acknowledged to keep the indoor environment stable. The researchers' thermal analysis indicated seasonal temperature differences, with specific regard to humidity and evaporative temperature. Thomas and colleagues point out that room temperature is only one measure of room climate. Consideration must be given to evaporative, air, and radiant temperatures, as well as humidity. Evaporative temperature is of concern because premature skin is very permeable and highly susceptible to heat and fluid loss (Thomas et al., 2010).

Sherman et al. (2006b) note that the younger the gestational age of a baby, the less fat and glycogen has been stored for heat production. In addition, the body surface area-to-weight ratio is lower than most adults, which, along with skin permeability, promotes rapid heat loss or gain and water loss. Incubators and radiant warmer beds are the primary devices for keeping infants warm.

5.4.1.6 Examples of infant spaces in NICUs

Figures 5.33 to 5.45 are examples of infant spaces in NICUs in approximate chronological order. The location, design firm(s), and photo credit are provided. The examples reflect the wide range of options and transitions that have taken place over time.

5.4.2 *Family needs*

Family-centered care has been a trend in neonatal intensive care and is becoming an increasingly important factor when designing the NICU. Recent research suggests that proactive, family-integrated care has a positive impact on family and baby outcomes (O'Brien et al., 2013). When considering how to encourage families to stay with infant patients and participate in the care of infants, the perceptions and feelings of NICU families must be explored. A more thorough understanding of family needs will result in a more family-friendly environment. One very important need emerged in research conducted by Moore et al. (2003). Case studies of 11 units that supported family-centered care to varying degrees revealed the need for families to have unlimited access to their child. Saunders et al. (2003) conducted a before-and-after study of the impact of family-centered care protocols on outcomes but found no differences in clinical outcomes over a two-year period. However, surveys of staff and parents were not included in this study.

Figure 5.33: *Shands Hospital for Children at UF NICU, Gainesville, FL, 1988 (Architects: Flad Architects; Photo credit: Courtesy of Flad Architects)*