Use of Hearing Protection in Neonatal Intensive Care Unit Patients: A Systematic Review of the Evidence

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Abstract: Neonatal intensive care unit (NICU) settings present neonates with many environmental hazards, including exposure to dangerous sound intensity levels. Noise levels in NICUs worldwide overwhelmingly exceed the recommendations for safe exposure by the American Academy of Pediatrics. Environmental modifications and staff behavioral changes have proved ineffective to sufficiently reduce infant noise exposure. A systematic review of the literature was undertaken to answer if earmuffs improve physiologic stability, behavioral response, and sleep behavior, which are markers of stress response in NICU patients. Seven databases were searched for pertinent records using a specific search protocol. Seven studies met the review's inclusion criteria and were examined for qualitative synthesis. This review supports using earmuffs to reduce neonate exposure to noise in the NICU as a viable intervention to improve physiologic stability and sleep and behavioral responses. Earmuffs are a minimally invasive, affordable, and effective option for attempting to comply with recommended noise guidelines. Moreover, earmuff use by NICU patients should be considered as a component of routine evidence-based practices when implementing development-centered care to minimize over-stimulation of NICU patients.

Key Words: NICU, noise, hearing protection, earmuff, infant, stress

Acronyms: AAP = American Academy of Pediatrics; ABR = auditory brainstem responses; ABSS = Anderson Behavioral State Scoring; HPD = hearing protection devices; NICU = Neonatal intensive care unit

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Introduction

Infants who require dedicated medical attention after birth are routinely admitted into a neonatal intensive care unit (NICU) due to maternal risk factors, delivery complications, and active disease. Often premature, these patients are not ready to cope with the external environment, let alone with stressors present in medical settings. Although necessary, the very medical care designed to sustain life may also pose a threat to the neurodevelopment and physiologic stability of neonates. Life-sustaining care is often accompanied by excessive levels of noise, which can lead to elevated stress responses in critically-ill infants. Developmentally supportive care has been proposed as a means to decrease negative effects on infants and optimize their development (Aucott, Donohue, Atkins & Allen, 2002) by regularly assessing the neurodevelopmental condition of an infant, minimizing environmental stressors, promoting infant rest, and maintaining a positive energy balance (Hamilton & Redshaw, 2009). Individual infant hearing protection has been proposed as a minimally-invasive and cost-effective way to reduce the effect of noise on infant stress response.

This systematic review was designed to assess the effectiveness of using individual infant hearing protection to reduce stress responses. The results of this analysis are particularly relevant to hearing healthcare providers due to their role as consultants on matters relating to noise, hearing protection devices (HPD), and creating NICU protocols. Audiologists perform follow up assessments for failed newborn hearing screens and to monitor for hearing changes in at-risk infants; as such, they will provide information to caregivers and pediatricians regarding ongoing risks.

Noise in the NICU is a pervasive environmental stressor to infants. For an infant with compromised medical status, noise exposure can be a hazard to their global health. Neonates in the NICU depend on healthcare professionals to identify and manage sources of stress, including noise. The American Academy of Pediatrics (AAP) lists validated and reliable behavioral indicators (e.g., body movement, crying, sleep) and physiologic indicators (e.g., changes in heart rate, respiratory rate, blood pressure, oxygen saturation, and cortisol levels) that can be used to assess and manage infant pain and stress (Lemons et al., 2000).
They recommend minimizing noxious environmental stimuli for all neonates and continuous use of pulse oximetry and frequently monitoring vital signs to detect stress. These sequelae of toxic stress in a newborn are all the more serious in NICU populations who are already at risk for developmental complications. Audiologists, in particular those working alongside NICU nursing staff, should be familiar with the noise stressors this environment presents in order to make recommendations that can mitigate infant noise exposure and associated stress responses.

Noise is one of the major iatrogenic environmental hazards neonates face in the NICU (Lai and Bearer, 2008). Sound levels measured in NICUs between 1979 and 2005 range from 70 dB up to 117 dB* (Brown, 2009). According to the U.S. Environmental Protection Agency (1974) the sound levels in hospital environments should not exceed 45 dB* in the daytime and 35 dB* at night. Although recently reported sound pressure levels vary tremendously (Pinheiro, Guinburg, Nabuco, & Kakehashi, 2011) they overwhelmingly and consistently surpass the levels recommended by the AAP. Parra, de Suremain, Audeoud, Ego, and Debillon (2017), concluded that NICU noise exceeds recommended limits within incubators. This may seem counterintuitive given that incubators are viewed as safe spaces, but may be explained by reverberation, noise causing peak sounds inside the incubator, and equipment and infant noise. Despite several decades of continuous efforts to control sounds in NICU environments, the noise levels remain at levels that pose a threat to infants with compromised health.

The link between exposure to excessive noise and resulting stress responses is well known. Heart rate increased in both full-term and preterm infants in response to a 90 dB, 2.5-second buzzer (Field, Dempsey, Hatch, Ting, & Clifton, 1979), with only the full-term infants demonstrating an ability to habituate to the buzzer over time. Closely related to heart rate, oxygen saturation is the percentage of oxygen available in blood. According to the clinical guidelines of The Royal Children's Hospital Melbourne (2016), oxygen saturation levels should be targeted within the range of 91–95% in both preterm and term neonates in order for the body and internal organs to perform essential functions. Noise may cause alteration in oxygen saturation and increased oxygen consumption secondary to elevated heart and respiratory rates (Morris & Bose, 2000; Wachman & Lahav, 2011), and may lead to a decrease in the amount of calories available for growth. Mean oxygen saturation in premature newborns during a daily, designated silence period (94.22%) were significantly higher than before (92.80%) the silence period (Taheri, Abbasi, Abdeyazdan and Fathizadeh, 2010). Infants housed within incubators causing high environmental noise (Parra et al., 2017) had increased heart rates and decreased oxygen saturation (Cardoso, Kozlowski, Lacerda, Marques, & Ribas, 2015). Slevin, Farrington, Duffy, Daly, & Murphy (2000) reported that neonates’ median diastolic blood pressure, mean arterial pressure, and infant movements were all reduced when the NICU environment was deliberately altered by reducing light, noise, infant handling, and staff activity for a specified time period. Lastly, weight gain is monitored closely in the NICU because promoting growth is a crucial aspect of managing these patients’ care and development. It is generally accepted that neonatal stress leads to energy expenditure, which in turn may result in altered growth and delayed discharge from the NICU (Farrell & Nicoteri, 2007). Availability of an intervention to reduce at least one source of infant stress and that could be used while the infant is housed in an incubator would lead to more stable physiologic response and increased weight gain. Given the obstacles to implementing silent periods and operating under the recommended noise levels, HPDs such as earmuffs can be considered a comparatively simple alternative. When NICU nurses were polled on the subject of earmuff use, 72% reported that NICU noise is too loud and 100% believed this intervention was not hazardous to the infants (Abdeyazdan, Ghassemi, & Marofi, 2014).

Compared to full term infants, the behavior of preterm infants is notable for signs of stress including motor responses (tone, activity, and posture) and states of central nervous system arousal (drowsiness, alertness, and crying; Mulligan LaRossa, 2018). The Anderson Behavioral State Scoring (ABSS) system is a measure that evaluates preterm infants’ behavioral states and provides information on infant sleep so sleep quality can be measured quantitatively (Burroughs, Asonye, Anderson, Shanklin, & Vidyasagar, 1978; Parmelee and Stern, 1972). Essential brain functions related to neonatal neurodevelopment take place during non-rapid eye movement period of sleep (NREM; Peirano, Algarin, & Uauy, 2003). Therefore, a variable of interest to monitor neurodevelopment is the total time spent in NREM sleep as measured by electroencephalograms.

In adults, when noise is combined with other factors, such as ototoxic medications, its potential to cause damage to hearing organs increases (Cone et al., 2017). This is true for infants as well. Bernard (1981) detected hearing loss using auditory brainstem responses (ABR) in preterm neonates exposed to aminoglycosides. The amount of shift in ABR wave V was correlated to the aminoglycoside dose administered per kilogram of body weight. In 2007, Rees confirmed that preterm infants in NICU who received aminoglycosides 7 or more days while exposed to noise levels produced by mechanical ventilation (> 80 dBA for > 30 minutes) had a 68% probability of developing hearing loss.

The direct connections between exposure to excessive environmental noise and increased stress in newborns highlight the need to implement sound reduction practices in NICUs. One tactic targets the professionals providing care to critically ill neonates. However, a dedicated education program for NICU staff failed to produce a dB weighting unit was not specified.
An individualized option to reduce infant exposure to noise is the use of personal hearing protection such as earmuffs. The most widely used HPD in routine infant care and research are the MiniMuffs® (Natus Medical Incorporated), supra-aural noise attenuators designed specifically for premature infants. Natus Medical Inc. states these attenuators reduce sound levels by at least 7 dB. An alternative to a supra-aural HPD is a silicone earplug that must be molded to the shape of the ear and inserted in the concha and auditory canal.

A systematic review of the literature was undertaken to determine if personal hearing protection use by NICU patients improves physiologic stability, behavioral response, and sleep behavior, which are markers of stress response. Initial review of the available literature identified one study using silicone earplugs in NICU infants (Turk, Williams, & Lasky, 2009). However, this study's outcome measure was restricted to infant weight gain during the NICU stay and performance on developmental tests at 18–22 months of age. We wished to determine if evidence supports the use of HPD based on physiologic measures, which could justify the use of developmentally supportive care in NICUs. Therefore, Turk et al.’s conclusions were not included in further analyses.

Method

Time Frame
This review only included studies published between 1997 and April 2017. According to the Global Marketing department of Natus Medical Incorporated, the MiniMuff® has been on the market since 1993, without any major design changes since its release (G. Accetturo, personal communication, May 10, 2017).

Search Strategy
A systematic search of records was completed using six databases: CINAHL Complete, MEDLINE, Scopus, ComDisDome, Access Medicine, and Nursing Reference Center. The search queries were:

1. “(NICU) AND (noise reduction)”
2. “(NICU) AND (earmuff)”
3. “(NICU) AND (earplug)”

Secondly, the references cited by articles that met inclusion criteria (see Table 1) were searched to identify additional records, which yielded three results. Figure 1 depicts the complete search process. Study selection was guided by the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement,” by Moher, Liberati, Tetzlaff, Altman, & Prisma Group (2009). Article titles and abstracts were subjected to the inclusion criteria. The record screening was followed by reading the full texts to identify required inclusion criteria.

Figure 1. Identification of included studies.

Selection Criteria
Selection of records began by screening article titles and abstracts for relevancy. Those passing the initial screen were read in full to identify inclusion/exclusion criteria (Table 1). Inclusion criteria were: NICU population, English language of publication, published on or after
use of MiniMuffs®, and published in peer-reviewed sources. Studies had to include either a physiologic and/or behavioral measure as an outcome measure. Physiologic measures included heart rate, respiratory rate, blood pressure, oxygen saturation, body temperature, weight gain, time in rapid eye movement (REM) sleep, and time in non-rapid eye movement sleep (NREM). Behavioral outcome measures included frequency of motor responses and scores on the ABSS (Burroughs et al., 1978; Parmelee & Stern, 1972). All articles were screened and reviewed by the first author to ensure all inclusion criteria were met.

**Level of Evidence and Quality Assessment**

Each study meeting inclusion criteria was assigned a level of evidence and study quality. Level of evidence was determined based upon the guideline published by The Oxford Centre for Evidence-Based Medicine (Phillips et al., 1998). The included studies were each categorized as a Level 1b for individual randomized controlled trial. Study quality was determined using the scheme developed by the American Speech-Language-Hearing Association (ASHA) National Center for Evidence-Based Practice in Communication Disorders (Cherney, Patterson, Raymer, Frymark, & Schooling, 2008). Records received a point for each quality indicator: assessor blinding, random sampling, group participant comparability, treatment fidelity, valid outcomes, significance, precision, and intent-to-treat. All included studies received 7 points, missing one point for assessor blinding.

**Table 1**

*Systematic Review Inclusion and Exclusion Criteria*

<table>
<thead>
<tr>
<th>Component</th>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Neonatal intensive care unit patients</td>
<td>Well-baby nursery patients, non-infant patients</td>
</tr>
<tr>
<td>Language</td>
<td>English</td>
<td>All other languages</td>
</tr>
<tr>
<td>Publication date</td>
<td>On or after 1997</td>
<td>1996 or earlier</td>
</tr>
<tr>
<td>Intervention</td>
<td>Noise exposure reduction using MiniMuffs® by Natus Medical Incorporated</td>
<td>Silicone ear plugs, other environmental or behavioral noise reduction strategies</td>
</tr>
<tr>
<td>Method</td>
<td>Published in peer-reviewed sources, meta-analyses, randomized controlled trials, cohort studies, case control, cross-sectional, retrospective and prospective studies</td>
<td>Theoretical papers, opinion-based editorials, reviews, qualitative studies, case studies, records with no statistical data reported, theses, and dissertations</td>
</tr>
<tr>
<td>Physiologic</td>
<td>heart rate, respiratory rate, blood pressure, O₂ saturation, temperature, weight gain</td>
<td>Any physiologic or behavioral outcome measure obtained more than 1 day after intervention. Pain index.</td>
</tr>
<tr>
<td>Outcome Measures</td>
<td>frequency of motor response, ABSS score, time in REM &amp; NREM sleep.</td>
<td></td>
</tr>
</tbody>
</table>

*Note: ABSS = Anderson Behavioral State Scoring; NREM = Non-rapid eye movement*  

**Table 2**

*Patient Characteristics*

<table>
<thead>
<tr>
<th>Authors</th>
<th>N</th>
<th>Gestational Age</th>
<th>Gender</th>
<th>Premature</th>
<th>APGAR at 5 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdoyazdan, Ghassemi, Marofi, &amp; Banjis (2014)</td>
<td>96</td>
<td>29–36 weeks</td>
<td>NR</td>
<td>Yes</td>
<td>≥ 7</td>
</tr>
<tr>
<td>Abdoyazdan, Ghassemi, &amp; Marofi (2014)</td>
<td>64</td>
<td>28–37 weeks</td>
<td>41 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23 F</td>
<td>Yes</td>
<td>≥ 7</td>
</tr>
<tr>
<td>Abujarir et al. (2012)</td>
<td>100</td>
<td>&gt; 26 weeks</td>
<td>54 M</td>
<td>Not all</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>46 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aita et al. (2013)</td>
<td>54</td>
<td>28–32 weeks</td>
<td>26 M</td>
<td>Yes</td>
<td>≥ 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duran et al. (2012)</td>
<td>20</td>
<td>29.9 ± 2.1 weeks</td>
<td>6 M</td>
<td>Yes, &lt; 1500 g</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Khalesi et al. (2017)</td>
<td>36</td>
<td>28–32 weeks</td>
<td>22 M</td>
<td>Yes</td>
<td>≥ 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varvara et al. (2016)</td>
<td>32</td>
<td>≥ 31</td>
<td>22 M</td>
<td>Not all</td>
<td>&gt; 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: NR = not reported*
Data Synthesis
All studies in this review used the MiniMuff® as the HPD. Methods, outcome measures, and statistical reporting varied across the selected studies, which prevented the completion of a meta-analysis. Prematurity status was not homogeneous, intervention duration varied, noise level and total exposure differed, and dB weighing was not provided. Data were entered into summary tables and a narrative synthesis was used to determine if clinical use of earmuffs on NICU patients should be recommended. In particular, it was noted whether the authors of each study recommended or did not recommend the use of earmuffs.

Results
Seven studies met inclusion criteria. Table 2 summarizes patient characteristics (e.g., gestational age, gender) and Table 3 summarizes intervention variables and results (e.g., intervention schedule, outcome measures). Six

Table 3

<table>
<thead>
<tr>
<th>Authors</th>
<th>Intervention Program</th>
<th>Intervention Schedule</th>
<th>Duration</th>
<th>Outcomes Measures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdeyazdan, Ghassemi, Marofi, &amp; Barjots (2014)</td>
<td>1. Earmuffs on 2. Control 3. Silence (staff behavior modification)</td>
<td>9–11 AM and 4–6 PM for two consecutive days; 11 PM–5 AM for ten consecutive nights</td>
<td>68 hours</td>
<td>Weight gain; Frequency of MR (tremor, twitch, startle reflex)</td>
<td>1. 83.7 g weight gain; reduction in MR during and 1 hour after earmuffs 2. 7.94 g weight gain; increased MR 3. 59.1 g weight gain; reduction of MR only during silence period</td>
</tr>
<tr>
<td>Abdeyazdan, Ghassemi, &amp; Marofi (2014)</td>
<td>1. Earmuffs on 2. Control</td>
<td>9–11 AM and 4–6 PM for two consecutive days</td>
<td>8 hours</td>
<td>HR, arterial O₂ saturation, RR, and MR frequency</td>
<td>Intervention group had increased O₂ saturation, decreased RR and HR, and a reduction of MR. Control group had decreased O₂ saturation, increased HR, and increased number of MR.</td>
</tr>
<tr>
<td>Abujarir et al. (2012)</td>
<td>1. Earmuffs on 2. Control</td>
<td>From time of admission until 72 hours</td>
<td>72 hours</td>
<td>HR, systolic BP, diastolic BP, RR, temperature and O₂ saturation</td>
<td>Earmuff group had significantly lower HR and RR, and higher O₂ saturation and systolic BP. No significant difference in temperature control and diastolic BP.</td>
</tr>
<tr>
<td>Aita et al. (2013)</td>
<td>Eye goggles and earmuffs applied to infants in a crossover trial with a 29-hour wash out</td>
<td>6 AM–12 PM</td>
<td>8 hours (4 hours in each condition)</td>
<td>Mean/min/max HR, HR variability, O₂ saturation, ECG low frequency power (sympathetic activation), high frequency power (parasympathetic activation, RR)</td>
<td>Significantly higher maximum HR and lower HR power during intervention. No difference in mean HR, minimum HR, and O₂ saturation during control period.</td>
</tr>
<tr>
<td>Duran et al. (2012)</td>
<td>Earmuffs applied in crossover trial</td>
<td>2 days with and 2 days without earmuffs for 4 consecutive days</td>
<td>56 hours (48 hours in each condition)</td>
<td>Body temperature, BP, HR, RR, O₂ saturation and ABSS</td>
<td>Mean body temperature, HR, RR, BP, and O₂ saturation not statistically different between conditions. Infants with earmuffs were more frequently in quiet sleep and less frequently in active sleep. Infants without earmuffs were more frequently in awake or fussy/cry state.</td>
</tr>
<tr>
<td>Khalesi et al. (2017)</td>
<td>Earmuffs applied in crossover trial, infants served as own control.</td>
<td>8 AM–4 PM during two consecutive days</td>
<td>16 hours (8 hours in each condition)</td>
<td>Body temperature, HR, RR, systolic BP, diastolic BP, O₂ saturation, and ABSS</td>
<td>When wearing earmuffs infants had significantly lower RR and HR, higher O₂ saturation, and lower ABSS. More infants with earmuffs were in quiet sleep.</td>
</tr>
<tr>
<td>Varvara et al. (2016)</td>
<td>Day 1: baseline conditions Day 2: earmuffs Day 3: incubator cover</td>
<td>8 AM–12 AM for three consecutive days</td>
<td>48 hours (16 hours each condition)</td>
<td>Time in Non-REM, REM, and total sleep duration.</td>
<td>Total time of Non-REM sleep was significantly higher with earmuffs than without. No significant difference in REM time or total sleep duration.</td>
</tr>
</tbody>
</table>

Note: MR = motor response; HR = heart rate; RR = respiratory rate; BP = blood pressure; ECG = electrocardiogram; ABSS = Anderson Behavioral State Scoring System; REM = rapid eye movement.
All but two studies (Abdeyazdan, Ghassemi, & Marofi, 2014; Abdeyazdan, Ghassemi, Marofi, & Berjis, 2014) reported that infants were cared for in incubators during the study periods, but did specify that infants were in the NICU of the hospital, not in individual rooms. Based on this information we presume the environment was similar for infants in all studies. The majority of studies made sound pressure level recordings (Abdeyazdan, Ghassemi, & Marofi, 2014; Abujarir, Salama, Greer, Al Thani, & Visda, 2012; Aita, Johnston, Goulet, Oberlander, & Snider, 2013; Duran et al., 2012; Varvara, Effrossine, Despoina, Konstantinos, & Matziou, 2016) all of which were above the recommended value of 45 dB SPL (Committee on Environmental Health, 1997). Khalesi, Khosravi, Ranjbar, Godarzi, & Karimi (2017) did not make sound pressure level recordings. Each of the included studies supported the use of earmuffs to protect infants in the NICU from excessive noise levels (Table 4).

### Table 4

<table>
<thead>
<tr>
<th>Authors</th>
<th>Conclusions</th>
<th>Support/Reject interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdeyazdan, Ghassemi, &amp; Marofi (2014)</td>
<td>Both interventions led to fewer motor responses and improved weight gain. This effect was more pronounced in the earmuff group.</td>
<td>Support, particularly in wards facing executive problems with implementing silence</td>
</tr>
<tr>
<td>Abujarir et al. (2012)</td>
<td>Positive effect of wearing earmuffs in four common vital signs in sick newborn infants.</td>
<td>Support as routine care in the NICU.</td>
</tr>
<tr>
<td>Aita et al. (2013)</td>
<td>More stress responses when infants were wearing eye goggles and earmuffs than when not wearing them.</td>
<td>Reject wearing eye goggles and earmuffs as an intervention to reduce light and noise exposure.</td>
</tr>
<tr>
<td>Duran et al. (2012)</td>
<td>Noise reduction with earmuffs was associated with significant improvement in behavioral state of ABSS.</td>
<td>Support earmuff use to improve sleep efficiency and increase time of quiet sleep.</td>
</tr>
<tr>
<td>Khalesi et al. (2017)</td>
<td>Noise level reduction in NICUs by using earmuffs improved neonates’ physiological stability and behavioral states of ABSS.</td>
<td>Support using earmuffs in neonatal intensive care units</td>
</tr>
<tr>
<td>Varvara et al. (2016)</td>
<td>Providing low noise levels within the NICU will improve structural organization of sleep with more prolonged NREM periods.</td>
<td>Partially support intervention. Authors believe earmuffs are not practical clinical approach and that more research on sleep is needed.</td>
</tr>
</tbody>
</table>

**Discussion**

Technological innovation and improvement in modern neonatal medicine have allowed for a reduction in the mortality rates of newborns that receive intensive care (Chow et al., 2015). Although overwhelmingly positive, these interventions have made the NICU a high sensory environment that may increase infants’ stress, placing their neurological development at increased risk. This systematic review focused on evaluating the use of HPDs to reduce the harmful effects of noise on the developing infant in the NICU. The seven studies included in this review reported physiologic stability and behavioral and sleep data during controlled periods of HPD (specifically earmuffs) use by NICU patients.

**Physiologic Stability**

**Heart rate.** Five out of the seven studies reported heart rate as an outcome measure. Out of those, three reported significantly lower heart rates during earmuff use compared to control periods without earmuffs (Abdeyazdan, Ghassemi, & Marofi, 2014; Abdeyazdan, Ghassemi, Marofi, & Berjis, 2014; Khalesi, Khosravi, Ranjbar, Godarzi, & Karimi, 2017). The remaining two studies found no difference in heart rate with and without earmuff use (Aita et al., 2013; Duran et al., 2012). Given that infants with lower Apgar scores (≤ 5 at 5 minutes) have more variable heart rate responses to sound, an intervention that stabilizes heart rate by reducing stress response to sounds is promising (White-Traut et al., 2009).

**Respiratory rate.** In the presence of persisting, inappropriately intense or complex stimulation, an increase in respiratory rate serves as an autonomic sign of stress (Emory University, n.d.). The same three studies listed reporting heart rate (Abdeyazdan, Ghassemi, & Marofi, 2014; Abdeyazdan, Ghassemi, Marofi, & Berjis, 2014; Khalesi et al., 2017), reported significantly decreased respiratory rates when infants were protected from noise using earmuffs. A fourth study, Duran et al. (2012), found no difference between with and without earmuff conditions. Acutely ill infants, when exposed to continuous
stressors, experience increased heart and respiratory rates. Implementing earmuff use can significantly lower respiratory rates.

**Oxygen saturation.** Abdeyazdan, Ghassemi, & Marofi (2014a), Abdeyazdan, Ghassemi, Marofi, & Berjis (2014), and Khalesi et al. (2017) reported significantly increased oxygen saturation levels when infants were using earmuffs compared to no-earmuff conditions. Aita et al. (2013) and Duran et al. (2012) did not find significant differences in oxygen saturation levels with earmuff use.

**Blood pressure.** Three out of the seven selected articles measured infant blood pressure. One found a significant improvement (i.e., a decrease) in mean blood pressure, but not in diastolic blood pressure (Abujarir et al., 2012). Duran et al. (2012) and Khalesi et al. (2017) failed to find a significant effect on this vital sign with the use of earmuffs. One record is insufficient to validate blood pressure measurement as an acceptable and useful method of tracking physiologic stability as a result of earmuff use. Blood pressure change is not a good method of screening for illness and can be difficult to track reliably on neonates as artifact from movement and crying is common (Puchalski, 2011). Furthermore, the accuracy of selecting the appropriate upper arm, forearm, and calf cuff size for neonates by visual assessment is low (Devinck, Keukelier, Savoye, Desmet, & Smets, 2013).

**Temperature.** Three studies included body temperature as an outcome measure, yet none found this to be significantly impacted by earmuff use (Abujarir et al., 2012; Duran et al., 2012; Khalesi et al., 2017). Although body temperature is one of the fundamental variables for health monitoring of premature NICU infants, infant body temperatures are not yet locked to time of day as are adults’, and they vary with sleeping and feeding patterns (Anderson, Petersen, & Wailoo, 1990). As such, body temperature would not be a reliable indicator of improved physiologic stability as a result of earmuff use.

**Weight gain.** Abdeyazdan, Ghassemi, Marofi, & Berjis (2014) have been the only ones to document the effect of noise reduction by earmuff on weight gain in NICU patients. They demonstrated a meaningful and statistically significant increase in weight gain in the earmuff-wearing group when compared to non-earmuff-wearing controls. It is important to note that this difference was between the first and the tenth day of the study. Although weight and weight gain are recorded accurately and often in NICUs, not all patients remain in intensive care for such a long duration. More research is needed to compare weight gain during shorter periods of time and to determine if this effect can be attributed to earmuff use.

**Electrocardiogram findings.** Aita et al. (2013) reported the low- and high-frequency power from the spectral analyses of electrocardiograms as an outcome measure. Preterm infants had lower high-frequency power while wearing earmuffs and eye goggles, suggesting that they had more stress responses, which was interpreted as higher parasympathetic activation. However, this relationship may be due to handling of the infants during the four-hour study periods. Touching the infants with their vision occluded may have exacerbated their stress response. According to the authors, high-frequency power is synchronous with respiratory rate. Respiratory and heart rate are more reliably measured and easier to obtain without the need of electrocardiogram equipment, so low- and high-frequency power would not be recommended as effective indicators of physiologic stability as a result of earmuff use.

**Summary of physiologic markers.** Heart rate, respiratory rate, and oxygen saturation level are good markers of the effect of HPD use and are vital signs routinely monitored in the NICU. Blood pressure and body temperature are unreliable indicators of stress minimization as an outcome of HPD use.

**Non-Vital and Behavioral Responses**

**Frequency of motor response.** Infants manifest behavioral stress responses to noise by moving, fussing and crying. Abdeyazdan, Ghassemi, & Marofi (2014) and Abdeyazdan, Ghassemi, Marofi, & Berjis (2014) found a significant reduction in motor responses (startle, tremor and twitch) during the use of earmuffs as compared to before use. Abdeyazdan, Ghassemi, & Marofi (2014) reported that this reduction continued immediately after and for one hour after earmuff use. Abdeyazdan, Ghassemi, Marofi, & Berjis (2014) reported a reduction in behavioral responses during the use of earmuffs. Reduced frequency of motor responses is an indicator of fewer stress reactions and decreased energy consumption.

**ABSS.** Two studies used the ABSS system to more formally describe infant behavioral responses. Duran et al. (2012) and Khalesi et al. (2017) reported that preterm infants using earmuffs were more frequently observed in the quiet sleep state of ABSS compared to those without earmuffs. Khalesi et al. (2017) concluded that the ABSS was lower for infants with earmuffs as compared to those without.

**NREM and REM data.** Varvara et al. (2016) employed a quantitative approach to measuring infant sleep quality. Infants’ time in NREM sleep increased when sound exposure was reduced, which in turn likely results in better neurodevelopmental outcomes for the patient and improved central nervous system maturation.

**Non-vital and behavioral summary.** Earmuff use by NICU patients leads to reductions in the frequency of motor responses, lower (i.e., improved) ABSS scores, and increased sleep efficiency.

**Aggregated Conclusions**

None of the studies using only earmuffs reported detrimental effects on the infants. Neonates showed improvement in physiologic and/or behavioral responses.
when earmuffs alone were used as an intervention to decrease stress responses. Earmuffs most often had a beneficial effect on heart rate, respiratory rate, and oxygen saturation levels. Aggregated conclusions support use of earmuffs to protect infants from complications of noise pollution in NICU. Furthermore, infants not wearing earmuffs were observed in some instances to have poor and/or unstable physiologic behavioral responses throughout the day. Abujarir et al. (2012) note that some vital signs do not differ significantly in the first six to twelve hours of earmuff use which may be because infants are handled more often upon NICU admission and that infants need more time for adaptation to the extra-uterine environment.

The study that used both eye goggles and earmuffs to reduce preterm infants’ exposure to light and noise does not recommend this intervention for neonatal practice (Aita et al., 2013). The authors note that controlling these patients’ exposure to noise and light remains an essential part of developmental care, but the combined use of goggles and earmuffs actually adds to infants’ stress.

Duran et al. (2012) state that earmuffs were helpful to improve sleep efficiency, which is important for the healthy neurodevelopment of this population in question. To that, Varvara et al. (2016) add that lower noise improves the structural organization of sleep, particularly NREM sleep, during which synapses are formed for specific functions and which constitutes an integral part of memory and learning process.

**Implementation**

Clinical interventions must be strongly guided by evidence that supports patient benefit as well as the practicality of its implementation. Abdeyazdan, Ghassemi, & Marofi (2014) measured NICU nurses’ attitude about the use of earmuffs in premature infants in order to lower the stress imposed by noise. The majority of nurses surveyed (72%) perceived the noise in the NICU to be too loud, believed earmuffs were beneficial to the infants (64%), and all of the staff agreed that earmuffs only interfered with routine care sometimes and posed no hazard to the infants.

Any change to the NICU environment requires time and teamwork. NICU staff may be more likely to accept and implement change when they have contributed to the change process (Bremmer, Byers, & Kiehl, 2003). Staff may also benefit from evidence-based education programs in order to promote behaviors and interventions that prevent over-stimulating NICU patients (Aita & Goulet, 2003).

**Conclusion**

Analysis of the seven studies that examined the efficacy of using neonatal earmuffs to reduce infant stress in the NICU support this as a viable intervention. None of the studies using only earmuffs reported detrimental effects on the infants. Neonates had improved physiologic stability, sleep, and behavioral responses. Earmuffs are a minimally invasive, affordable, and effective option for complying with recommended noise guidelines (Committee on Environmental Health, 1997). Moreover, earmuff use by NICU patients should be considered as part of the routine evidence-based practices when implementing development centered care. This endorsement is in line with recommendations by the American Academy of Pediatrics to evaluate and reduce the stress experienced by neonates using validated measures and appropriate environmental and nonpharmacological (behavioral) interventions (Lemon et al., 2000).

When striving to provide a developmentally supportive environment, facilities should consider the following physiologic measures as reliable indicators of stability: heart rate, respiratory rate, and oxygen saturation levels. Stable or improved responses should not be expected until at least six (but up to thirteen) hours after earmuffs are placed on the infant due to increased handling and need for habituation. Measurements should be made during earmuff use, not immediately after or hours later to accurately reflect changes in vital signs.

The ABSS can reliably track behavior and sleep information in infants using earmuffs, particularly when NICU staff adheres to its recommended schedule and administration instructions. Simultaneous earmuff and goggle use is not recommended until further research elaborates on the presumed increased stress response by infants of this dual stimulus reduction technique. However, incubator covers can be used in combination with earmuffs when it is necessary to minimize exposure to light.

Infants with the greatest number of risk factors for hearing loss are coincidentally the ones receiving specialized care in the NICU. A longer NICU stay means a longer duration to excessive noise. Currently, no studies have investigated whether a relationship exists between NICU noise, hearing loss, and auditory development.

Further research is needed to evaluate parameters beyond the benefit of earmuffs on infants’ immediate physiological and behavioral stability. Implementation in different facilities and across NICU levels would further refine the present recommendation. NICU staff perceptions of feasibility, practicality, job duty interruption and ability to adequately secure earmuffs on newborns should be examined.

A physiologic measure not evaluated by any of the seven included studies is salivary cortisol level. This biomarker of stress and/or diurnal rhythms can be collected from infants non-invasively and without causing additional stress (Neu, Goldstein, Gao & Laudenslager, 2007). Investigating cortisol level differences and stability during earmuff use would add to the existing knowledge of physiologic status. Finally, controlled trials should be conducted to assess the long-term effects of using earmuffs in the NICU on neurodevelopmental outcomes.
References


