

**Universal Newborn Hearing Screening in the NICU Population Using  
New Features of the Vivosonic Integrity ABR Unit: Assessing the Correlation Coefficient as a  
Function of the Number of Sweeps Collected.**

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Abstract

The Auditory Brainstem response (ABR) is the assessment tool used to perform newborn hearing screenings in the Neonatal Intensive Care Unit (NICU) at the University of Kansas Medical Center. In the past, ABR testing has been difficult in the NICU due to artifacts caused by the complex electrical environment and physiological noise produced by the infant. The Vivosonic Integrity is a new ABR recording unit that has implemented several new features to make testing more efficient and accurate by reducing artifact and testing time. These features include the patented Bluetooth wireless technology, Amplitude, Kalman weighted averaging, and the two-waveform recording system with correlation coefficient. This research evaluates these features to determine if the Vivosonic Integrity ABR provides distinct advantages for newborn hearing screenings in the NICU compared to previous testing equipment. 50 NICU infants (100 ears) were given newborn hearing screenings using the Vivosonic Integrity ABR. The results of this study indicate that the Vivosonic Integrity ABR recording unit is effective in managing electrical and muscular artifacts for NICU ABR testing. The advantages offered by these features included: 1) the testing environment did not have to be altered due to electrical artifact to perform newborn hearing screenings, and 2) accurate recordings were obtained regardless of whether or not the baby was awake, asleep, in a crib or running isolette. Thus, the Vivosonic Integrity is a valuable tool that will continue to be utilized for all Newborn Hearing Screenings in the NICU at the University of Kansas Medical Center.

## Introduction

The auditory brainstem response or ABR is an evoked neuro-electrical potential that is generated by the auditory nerve and brainstem 5 to 20 milliseconds following the onset of a transient acoustic stimulus (e.g., a broadband click). The ABR has been proven to be a successful technique for assessing hearing sensitivity in infants since the 1970's (Sininger et al, 2000). Since the 1980's, ABR testing has been used as a primary method for screening newborn infants' hearing (Joint Committee on Infant Hearing, 1983). The University of Kansas Medical Center Neonatal Intensive Care Unit (NICU) utilizes the ABR as the required method of testing for universal newborn hearing screenings.

The current ABR equipment used in the NICU (Bio-Logic NavPro) requires the subject to be quiet (relaxed and preferably asleep or sedated) to acquire a recording free of artifacts. These artifacts are physiological and or electrical potentials that can appear on the recording in addition to the ABR (e.g., electroencephalogram ((EEG)), electroculogram ((EOG)) electronystagmogram ((ENG)), electrocardiogram ((EEG))) and electromyogram ((EMG)) (Sokolov et al, 2006). The muscular artifacts can't be removed through filtering because their frequencies range (50-500 Hz) lies within that of the ABR (50-3000 Hz). In order to reduce the muscular artifact, the audiologist has to watch the infant and only collect data during periods of quiet and pause during periods of noise. Also, numerous sweeps (1000 - 2000) are average to produce the response.

One method of reducing both physiological and electrical artifact in ABR recordings is to employ the "artifact rejection" routine of the recording unit. This software is utilized to throw out sweeps containing artifact beyond a set value of the A-D convertor (Sokolov et al, 2006). Artifact has always been a limiting factor in ABR testing, especially in children. Getting a

newborn to sleep and/or lie still are often difficult and time-consuming tasks for the audiologist. A new ABR recording instrument, the Vivosonic Integrity, recently has emerged with features that are intended to “revolutionize” ABR testing by eliminating the environmental noise and physiological artifacts that have made ABR recordings a challenge in the past. These features aim to extend the clinical applicability and ease of ABR testing in electromagnetically harsh environments with non-relaxed patients, like the NICU, where the environment and patients are the most challenging.

The Vivosonic Integrity is the first and only ABR system to utilize Bluetooth wireless as a means to reduce noise and artifact. Conventionally, ABR systems have an interface module that houses the system’s hardware (differential amplifier, amplifiers for the simulating transducers (insert earphones), analog-to-digital A/D and digital-to-analog D/A converters). The interface module is then connected to the computer via a cable, which can result in the presence of electrical artifact in the recording. (Sokolov et al, 2006). Utilizing a Bluetooth wireless signal (low-energy, broadband digital signal) eliminates the electrical path between the computer and the amplifier. In addition to reducing electrical interference to the ABR recording, Bluetooth also provides a more flexible testing configuration. The interface module can be up to 30 feet from the computer, which allows for the infant to remain in a crib, stroller, or car seat during testing. (Sokolov et al, 2006).

In addition to Bluetooth, the Amplitrode, which is an AEP (auditory evoked potential) differential preamplifier contained in an air-tight plastic housing unit that is electrically shielded and grounded, was developed to reduce electrical and magnetic field artifacts. Historically, filtering has been performed after pre-amplification. However, the Vivosonic Integrity utilizes filtering prior to pre-amplification. The Amplitrode applies a 30 Hz high-pass and a 2 MHz low-

pass filter to the ABR signal prior to pre-amplification. The high-pass filter reduces physiological signals and the low-pass filter reduces radio-frequency signals. In addition, this electrode arrangement eliminates the use of the ground wire (Kurtz & Sokolov, 2004) and all AEP signals are amplified in-situ (“on the site” directly on the ground electrode). This results in the ability to optimize the gain at the preamplifier and reduce saturation and distortion.

Lastly, weighted averaging is the technique the Vivosonic Integrity utilizes to reduce the effects of the EMG artifacts. This technique uses a weighting system that weights the recording periods with more artifacts less than the periods of quiet (John, 2001). This is known as the Kalman Filter. The Kalman Weighted Filtering is a patented algorithm by Vivosonic and it estimates the error in each individual sweep based on the signal variance and is continuously updating the estimate. The estimated ABR signal has a decreased probability of error in the amplitude estimating at each latency. (Sokolov et al, 2006).

While the Bluetooth technology, Amplitude and use of the Kalman filter help to reduce artifact, the two waveform buffer system was added to the Vivosonic Integrity to decrease testing time. According to Hall (2006), “no single factor contributes more to confidence and accuracy in ABR analysis than waveform repeatability” (p.215). As a result, clinically, it has been recommended to repeat ABR waveforms in order to validate the presence of Wave V (Hood, 1998 & Stapellis 2000). In order for this to be achieved, thousands of averaged responses may be needed. The Vivosonic Integrity has a two waveform recording system with a correlation coefficient component that eliminates the need for repeating waveforms on the ABR. The two waveforms are collected simultaneously and each response is assigned to either Buffer A or Buffer B based on collection order (Buffer A, odd responses and Buffer B, even responses). Vivosonic technology assigns the responses in a way that the mean-squared difference between

the two averages approximates the mean-standard error. A correlation coefficient measures the strength of association between two variables. In this case, the two variables are Buffer A and Buffer B. The most common correlation coefficient, called the Pearson product-moment correlation coefficient, measures the strength (-1 to 1) of the linear association between variables where -1 indicates a negative association, 0 no association and 1 a positive association. The correlation coefficient determines if the waveforms are repeatable between two points, the peak and trough of Wave V on the ABR, which are identified on the waveform by the testing audiologist. The strength of association determines whether a second recording is necessary. Vivosonic recommends using a correlation coefficient of 0.6 (significance level = 0.05) or 0.7 (significance level = 0.02). The chosen significance level is based on personal preference. It should be noted that the correlation coefficient alone does not determine the presence of the ABR, only the repeatability between Buffers A and B. Research done by Steinman and Kurtz, has shown that this new method improves the tightness of the distributions. Tighter distributions result in a condition in which fewer averages are needed to determine when the signal is present (2008). This feature alone significantly decreases testing time and the risk of exposure for the infant to outside pathogens through interaction with the audiologist. This is important when working with the NICU population since most infants there are being treated for various medical conditions.

The Vivosonic Integrity appears to have all of the features necessary to make ABR testing more efficient and accurate by reducing artifact and testing time. However, this claim has yet to be verified clinically, especially in a NICU. This project involves using this instrument to perform ABR recordings in the KUMC NICU to determine if the Vivosonic does indeed offer distinct advantages when used for screening hearing function in newborns. These advantages can

include shortened testing time (and therefore cost) and more accurate measurement of the ABR leading to improved diagnoses and follow-up.

### Methods

All babies discharged from the Neonatal Intensive Care Unit at KU Medical Center are required to have universal newborn hearing screenings. Any baby admitted to KU Medical Center and resided in the NICU from January 1, 2011 to March 31, 2012 was eligible for inclusion in this study. However, not every baby in the NICU from those dates participated in the study because data collection was based on the availability of two well-trained individuals present at the time of testing. One individual would run the equipment and facilitate the newborn hearing screening, while the second individual would collect the study data. Two individuals were not always available to complete testing.

Based on the University of Kansas Medical Center NICU protocol, newborn hearing screenings are completed once the infants are considered medically stable and are as close to hospital discharge as possible. Pass Criteria for ABR are replicable Wave V's at expected latencies for 60 dB HL and 30 dB HL or 35 dB HL depending on the age at test. For infants who do not pass the ABR screening, OAE (otoacoustic emission) screening is conducted in order to obtain further information. Infants are referred for further testing if they do not pass their initial ABR screening.

### *Subjects*

Newborn hearing screenings were completed using the Vivosonic Integrity ABR on 50 NICU infants (N = 100 ears). The infant's ages at time of testing ranged from 32-53 weeks corrected gestation. 48 out of 50 infants passed their newborn hearing screening. Passing criteria was indicated when Wave V of the ABR was present at 60 dB nHL and 30 dB nHL and the

correlation coefficient between Buffer A and Buffer B was greater than 0.7. All Wave V ABR latencies were confirmed using the Boys Town Normative Data available in the Vivosonic software. One infant did not meet passing criteria in their left ear and one did not passing criteria in their right ear.

### *Study Procedures*

The Vivosonic Integrity ABR protocol used in this study was consistent with current practices and testing parameters that have been used previously for newborn hearing screenings in the NICU population at the University of Kansas Medical Center. Parameters for the ABR included an air-conduction click stimulus under ER-3A insert earphones, with rarefaction polarity, a click rate of 37.7 clicks per second and intensities of 30 dB nHL and 60 dB nHL. The low-pass filter was set to 1500 Hz with a 24 dB/octave roll off and the high-pass filter was set to 30 Hz with a 12 dB/octave roll off. Electrodes were placed on the infant's forehead and behind both mastoids. The non-inverting (+) Amplitrode was placed on the forehead electrode (Fz-frontal). When testing the right ear, the inverting (-) electrode was placed on the right mastoid electrode and the large ground Amplitrode was place on the left mastoid electrode. When testing the left ear, the Amplitrodes were reversed and the inverting (-) Amplitrode was moved to the left test ear. Impedances were tested and all were 5 kilohm or lower prior to beginning the ABR. Once testing was initiated the two points for the correlation coefficient calculation were established by placing the statistical start (SS) indicator on the peak and the statistical end (SE) indicator on the trough of Wave V on the ABR tracing. The correlation between Buffer A and Buffer B was computed between the start and end points on the waveform by the Vivosonic Integrity software. When determining the appropriate correlation coefficient to use, previous studies were examined. Sininger et al, used a value of 10 degrees of freedom for a 30 ms window and a 30 Hz low pass filter. Using this value and hypothesis testing, a correlation of 0.7 yields a t-value of 2.7 and an alpha significance of 0.02 (2000). Research by Marcoux used a correlation of 0.65 (2011). Since the accepted

correlation coefficient value varies among users and is based on personal preference for statistical significance, we will use 0.7 (which has a more strict significance level = 0.02) as our accepted cutoff value. Example tracings for a left ear newborn hearing screening with SS, SE, Wave V and Boys Town normative data displayed on the waveform can be viewed in Appendix A.

The following data was collected without stopping the ABR recording on all 50 infants.

1) The correlation coefficients at 250, 500, 750, 1000, 1250, 1500, 1750 and 2000 sweeps for 60 dB nHL and 30 dB nHL from right and left ears. 2) The infant's sleep status: awake, restless or asleep. 3) The infants testing location: crib, car seat, isolette, running isolette or parent/nurse holding the infant.

### *Data Analysis*

Due to the slight variability in accepted correlation coefficient values, the correlation coefficient cutoff was examined. The number of sweeps in which the correlation coefficients were consistently above 0.7 was tabulated for each intensity level (60 dB nHL and 30 dB nHL) for the right and left ears. The same was done using stricter correlation coefficient cutoffs of 0.8, 0.9 and 1.0. The results were then averaged to obtain the mean number of sweeps needed to meet each correlation coefficient cutoff criteria.

A paired samples t-test was conducted using 0.7 cutoff values for 60 dB nHL and 30 dB nHL to determine if there was a difference in mean number of sweeps between ears. An ANOVA analysis was conducted for 60 dB nHL and 30 dB nHL based on the 0.7 correlation coefficient cutoff mean sweeps to determine the whether the infant's status and location at the time of testing effected the number of mean sweeps needed to reach the 0.7 cutoff.

## Results

### *Correlation Coefficient*

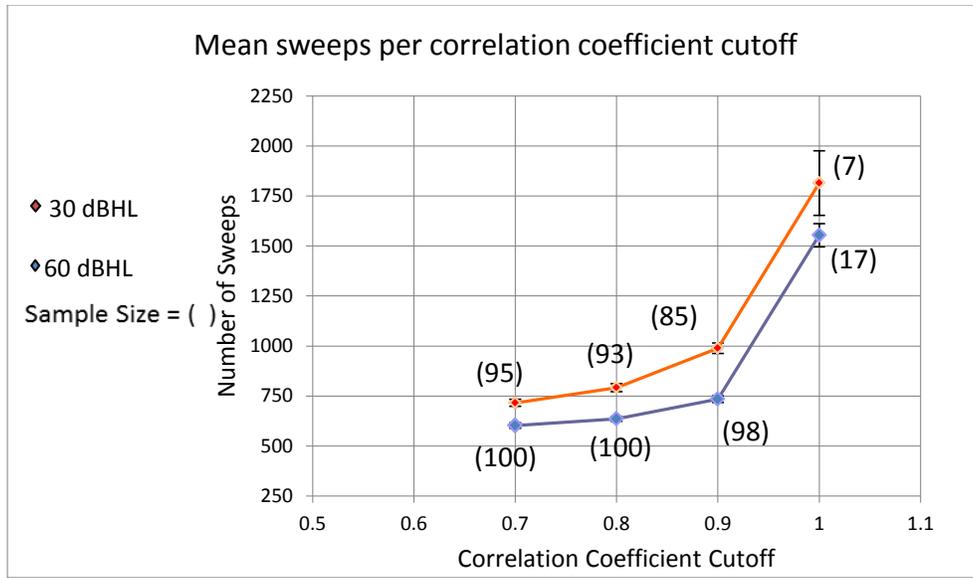
The first feature that was examined was the correlation coefficient. Vivosonic recommended a 0.7 cutoff value and we wanted to see if making our criterion more strict would change how many sweeps we needed to run for valid repeatable Wave V's. For the 60 dB nHL intensity level, all 100 ears met the 0.7 and 0.8 cutoff criteria, but not all subjects met the stricter criterion levels. 98 subjects met the 0.9 cutoff criteria and only 17 met the 1.0 cutoff criterion. For the 30 dB nHL intensity level, 95 ears met the 0.7 cut off criteria, 93 met the 0.8 cutoff criteria, 85 met the 0.9 criteria and 7 met the 1.0 cutoff criterion. Correlation coefficients of 1.0 were achieved significantly less due to the fact that 1.0 is the highest value that can be achieved. (Scatter plots of the original data: correlation coefficients by number of sweeps collected for 60 dB nHL and 30 dB nHL for right and left ears can be viewed in Appendix B and C). The mean number of sweeps needed to establish each cut values were calculated for both intensity levels. Increasing the correlation coefficient cutoff criteria increases the number of sweeps needed to achieve the cutoff, as predicted. The greatest difference in number of sweeps occurred for the 1.0 cutoff. Most likely due to the fact that only 17 ears reached 1.0 at 60 dB nHL and only 7 ears for 30 dB nHL. There was not much difference in mean number of sweeps between the 0.7 to 0.9 cutoffs, especially at the 60 dB nHL intensity level. Only 120 sweeps separated the 0.7 and 0.9 cutoffs. The Vivosonic Integrity runs so quickly that this difference in number of sweeps is obsolete during testing. Since there is relatively no difference in mean number of sweeps needed between 0.7 and 0.9, it can be determined that making our criterion more strict has no effect on testing time or the clinical decision on whether the infant passed the newborn hearing screening. Vivosonic's recommendation of a 0.7 correlation coefficient is adequate for our testing purposes.

**Table 1** summarizes the data.

Correlation Coefficient Cut Value	60 dB nHL				30 dB nHL			
	N = Total Number of Ears Tested	Mean Number of Sweeps	Standard Deviation	Coefficient of Variation	N = Total Number of Ears Tested	Mean Number of Sweeps	Standard Deviation	Coefficient of Variation
0.7	100	602.76	183.05	0.31	95	715.75	330.15	0.46
0.8	100	636.28	237.33	0.37	93	792.03	381.23	0.48
0.9	98	734.65	498.37	0.42	85	989.25	461.04	0.46
1.0	17	1553.59	891.37	0.32	7	1818.71	244.84	0.13

**Figure 1** below shows the mean number of sweeps per correlation coefficient cutoff for each criterion with their respective standard errors. The relationship between the number of sweeps needed for 60 dB nHL and 30 dB nHL intensity levels is fixed. The 60 dB nHL intensity level requires fewer sweeps across all correlation coefficient cutoffs. The closer you get to threshold, 30 dB nHL, the number of sweeps is more variable and more sweeps are consistently needed to achieve a correlation coefficient that is continuously above the desired cutoff value.

**Table 1- Mean sweeps needed to achieve correlation coefficient cutoffs for 60 dB nHL and 30 dB nHL** is significantly more variable for the 1.0 cutoff value. This is most likely due to the smaller number of subjects meeting the strictest 1.0 criterion. The coefficient of variation (cv = standard deviation/mean) was consistent across correlation coefficient cutoffs for both intensity levels, except at the 1.0 correlation coefficient cutoff for 30 dB nHL. This means that there is a consistent relationship between the mean number of sweeps and their standard deviations across cutoff values.



**Figure 1- Mean number of sweeps per correlation coefficient cut off for 60 dB nHL and 30 dB nHL**

*How many sweeps do we need to collect?*

Using the mean sweeps for the 0.7 correlation coefficient at 60 dB nHL and 30 dBnHL, we derived confidence intervals that will be used to guide our testing in the NICU and help us determine how many sweeps we need to collect for each of the two intensity levels. If Wave V of the ABR is present and the correlation coefficient is above 0.7, the recording can be stopped. The correlation coefficients would be above the cutoff for 95% of the subjects for the following ranges of sweeps. At the 60 dB nHL intensity level, our results indicate that 243.98 to 961.54 sweeps are needed for a 0.7 correlation coefficient cutoff. 98% of our subjects achieved a 0.7 correlation coefficient for the right and left ears by 961 sweeps for the 60 dB nHL intensity level. At the 30 dB nHL intensity level, 59.80 to 1371.70 sweeps are needed to achieve the 0.7 correlation coefficient cutoff. 92% of our subjects achieved a correlation coefficient for the right and left ears by 1371 sweeps for the 30 dB nHL intensity level. These ranges will be used as are benchmark for testing in the NICU.

*Ear Effect*

Once the 0.7 correlation coefficient was deemed adequate, we examined the 0.7 correlation coefficient results more closely. First, we wanted to determine if there was an ear effect. A paired samples t-test was conducted to compare the mean number of sweeps for right and left ears using the 0.7 correlation coefficient cutoff at 60 dB nHL. There was no significant difference in number of sweeps between right (M= 622.98, SD= 215.51) and left (M= 578.52, SD= 138.49) ear conditions for 60 dB nHL;  $t(47) = 1.236$ ,  $p = 0.223$ . There was also no significant difference in number of sweeps between right (M= 780.90, SD= 399.50) and left (M= 681.81, SD= 278.49) ear conditions for 30 dB nHL;  $t(47) = 1.386$ ,  $p = 0.172$ . There was however, a significant difference in the right ear when comparing 60 dB nHL intensity level (M= 622.98, SD= 215.51) to the 30 dB nHL intensity level (M= 780.90, SD= 399.50);  $t(47) = -2.568$ ,  $p = 0.013$ . The significant difference was also present for the left ear between the 60 dB nHL intensity level (M= 578.52, SD= 138.49) and the 30 dB nHL intensity level (M= 681.81, SD= 278.49);  $t(47) = -2.876$ ,  $p = 0.006$ . This confirms that more sweeps are needed for the 30 dB nHL intensity level than the 60 dB nHL intensity level.

#### *Effects of Sleep Status and Location*

Lastly, we wanted to look at the effects of the infant's sleep status (awake, restless, asleep) and location (crib, car seat, isolette, running isolette and parent/nurse holding) on the number of sweeps collected. To do this, we ran an ANOVA analysis for 60 dB nHL and 30 dB nHL to see if there was any difference within these conditions. The two-way ANOVA for 60 dB nHL showed a non-significant main effect for sleep status,  $F(2) = 0.235$ ,  $p = .791$ , partial  $\eta^2 = .005$ , a non-significant main effect for location,  $F(4) = 0.539$ ,  $p = .708$ , partial  $\eta^2 = .024$ , and a non-significant interaction,  $F(5) = 1.648$ ,  $p = .156$ , partial  $\eta^2 = .086$ . The two-way ANOVA for 30 dB nHL showed a non-significant main effect for sleep status,  $F(2) = 0.344$ ,  $p = .710$ , partial

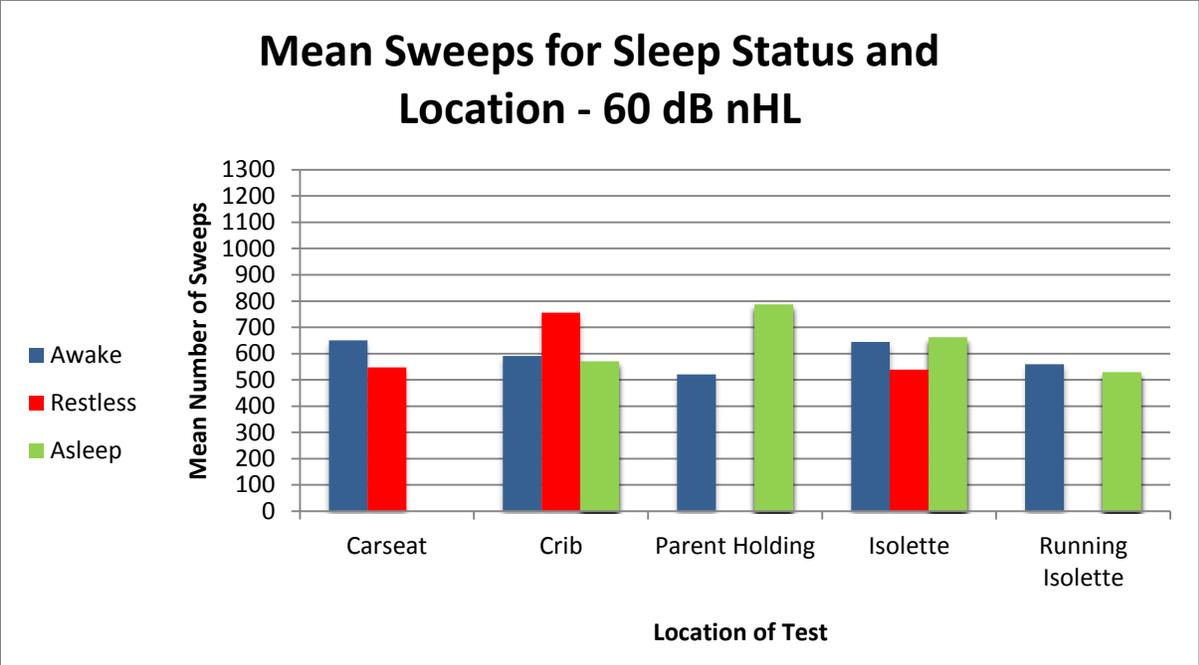
$\eta^2 = .008$ , a non-significant main effect for location,  $F(4) = 0.1.721$ ,  $p = .153$ , partial  $\eta^2 = .075$ , and a non-significant interaction,  $F(5) = .620$ ,  $p = .685$ , partial  $\eta^2 = .035$ . Both intensity levels revealed a non-significant interaction for sleep status and location. This is an important finding for our testing because it shows that there is no difference in number of sweeps needed to achieve a 0.7 correlation coefficient based on the infants sleep status or testing location. Consequently, no matter what status or location the infant is in at the time of testing, our testing procedures do not need to be altered to achieve the appropriate number of sweeps. **Table 2** below summarizes the results of the analysis.

Source	Type III Sum of Squares	Df	Mean Square	p
<b>60 dB nHL</b>				
Status	15376.81	2	7688.41	0.791
Location	70544.53	4	17636.13	0.708
Status * Location	269652.34	5	53930.47	0.156
<b>30 dB nHL</b>				
Status	78349.75	2	39174.87	0.710
Location	784309.86	4	196077.47	0.153
Status * Location	353174.90	5	70634.98	0.685

**Table 2- ANOVA Analysis**  
*Note: Significant at the  $p < 0.05$  level*

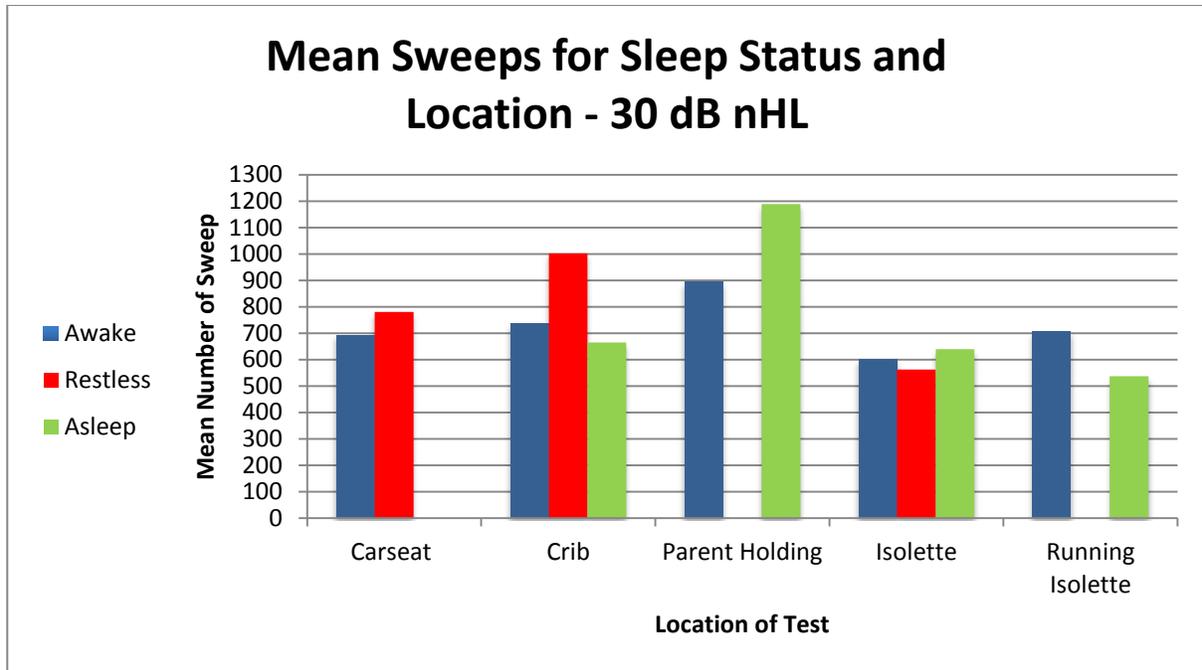
**Figure 2** below shows the mean number of sweeps for each condition (sleep status and location) for the 60 dB nHL intensity level. The asleep with parent holding condition required the greatest number

of sweeps to achieve a 0.7 correlation coefficient and the asleep in a running isolette condition required the fewest number of sweeps to achieve a 0.7 correlation coefficient. I would have predicted that the condition that would require the fewest number of sweeps would have been asleep in a crib. When asleep, the infant would produce the least amount of muscular artifact and a crib is a location that has no electrical artifact. This was the testing condition that was required for the previous Biologic ABR equipment that was highly sensitive to the effects of electrical and muscular artifacts. It is interesting that the running isolette, the location that produces the most electrical artifact, needed the fewest number of sweeps. This is possibly due to the fact that the running isolette produces an enclosed and temperature controlled environment that is the most comfortable for the infant. This is an important finding in our research. It shows that the Vivosonic Integrity ABR is very good at eliminating electrical artifact from the recording. The parent holding location also has the potential to produce high amounts of muscular artifact since the infant is being held and moved by the parent. So it is not surprising that this location required the most sweeps. Despite these differences seen on the graph, there is no significant difference between each interaction.



**Figure 2- Graph showing a comparison of the infant’s sleep status by location for the 60 dB nHL intensity level using a 0.7 correlation coefficient cutoff.**

When examining the same interactions (sleep status and location) for the 30 dB nHL intensity level, the asleep with parent holding condition still required the greatest number of sweeps. The condition that needed the fewest numbers of sweeps was again the running isolette, but this time in the sleeping condition. The isolette was the location that produced the most consistent number of sweeps needed to accomplish a 0.7 correlation coefficient across all sleep statuses. There was no consistent relationship between the awake or asleep status. This is important because this research shows that there is no difference in number of sweeps if the baby is awake or asleep. When comparing this to the previous Biologic ABR equipment, this is a significant change.



**Figure 3- Graph showing a comparison of the infant’s sleep status by location for the 30 dB nHL intensity level using a 0.7 correlation coefficient cutoff.**

Discussion

This research has provided some significant information about the Vivosonic Integrity ABR and its abilities in reducing electrical and muscular artifacts during testing. We were able to get valid passing newborn hearing screenings on infants that were awake and in electrically complex locations (running isolette and being held by a parent/nurse). This would have been impossible with previous Bio-Logic NavPro ABR equipment. In the past, it wasn’t uncommon to have to sit in the waiting room waiting for the infant to fall asleep so we could perform our newborn hearing screening.

Our results indicated that the Vivosonic recommended correlation coefficient cutoff of 0.7 was adequate. Using a stricter criterion did not require significantly more sweeps to be collected to achieve the desired cutoff. Since the Vivosonic Integrity runs so quickly, the difference in sweeps between 0.7 and the stricter criterion is obsolete.

There was no significant difference in number of sweeps between ears, which was to be expected. Perhaps one of the most useful findings in this study was that there was no significant difference in mean number of sweeps for the various testing conditions (sleep status and location). This shows that not only is the Vivosonic Integrity ABR able to achieve valid ABR results in complex testing environments, but the results for these complex environments are not significantly different than those from what was once considered the optimal testing environment (asleep in a crib).

The results have also provided us with a confidence interval for number of sweeps needed to achieve the 0.7 correlation coefficient cutoff for each intensity level. This confidence interval tells us what range of sweeps we need to shoot for to achieve the 0.7 correlation cutoff when performing ABRs in the NICU. Previously, we had no idea how many sweeps we needed to collect in order for our results to be valid.

Since the start of this research, the Vivosonic Integrity ABR has been utilized by other large hospitals for newborn hearing screenings. Wesley Medical Center in Wichita, Kansas, the largest birthing center in a 13-state region, also uses the Vivosonic Integrity ABR for universal newborn hearing screenings in their NICU population. In 2010, they had 6,383 live births and completed 178 ABR tests. They have also found that the Vivosonic Integrity is able to perform in the electrically and acoustically hostile NICU environment. Previously, they had to remove the infant from the NICU to perform the hearing screening. With the use of the Vivosonic Integrity, they can now accurately perform ABRs in the NICU (Walker, 2012).

The Vivosonic Integrity ABR was purchased through a grant from Sound Beginnings, the newborn hearing screening program in Kansas. Their overall intent was to reduce the number of infants that were lost to follow up by eliminating the infants that were referred for not passing their newborn hearing screening because the infant or environment was too noisy to complete testing. For future

research, it would be interesting to look at the refer rates for the Bio-Logic NavPro and their reason for referral and compare it to the refer rates of the Vivosonic Integrity to see if this goal has been achieved. It would also be interesting to do a direct comparison between ABR units and test each infant twice, once with the Bio-Logic NavPro and once with the Vivosonic Integrity, without altering the infants location or sleep status. Lastly, it would be interesting to evaluate the differences in ABR units when collecting toneburst ABRs instead of a click stimulus.

### Conclusions

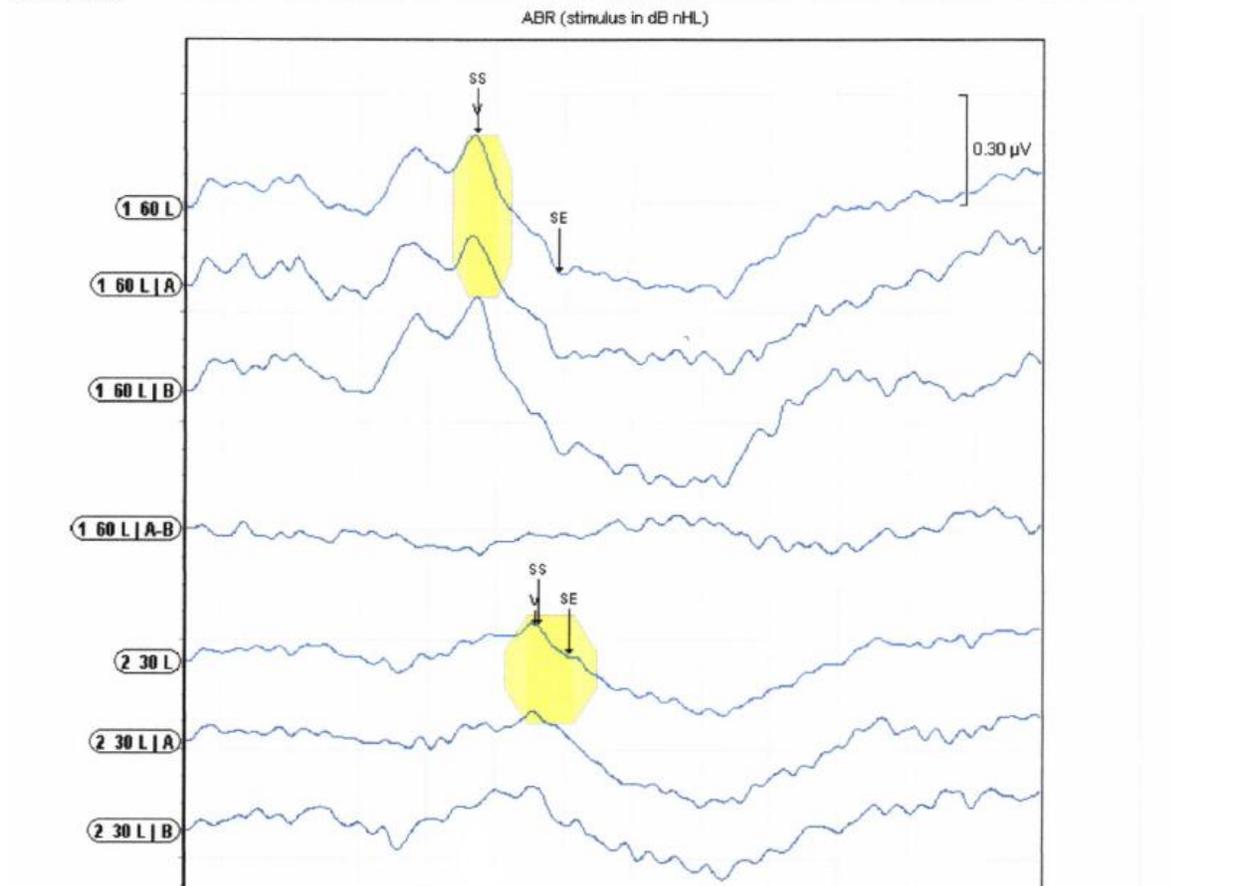
The results of this study indicate that the Vivosonic Integrity ABR recording unit is effective in managing electrical and muscular artifacts for NICU ABR testing. The advantages offered by these features included: 1) the testing environment did not have to be altered due to electrical artifact to perform newborn hearing screenings, and 2) accurate recordings were obtained regardless of whether or not the baby was awake, asleep, in a crib or running isolette. Thus, the Vivosonic Integrity is a valuable tool that will continue to be utilized for all Newborn Hearing Screenings in the NICU at the University of Kansas Medical Center.

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## Appendix A

### ABR GRAPH



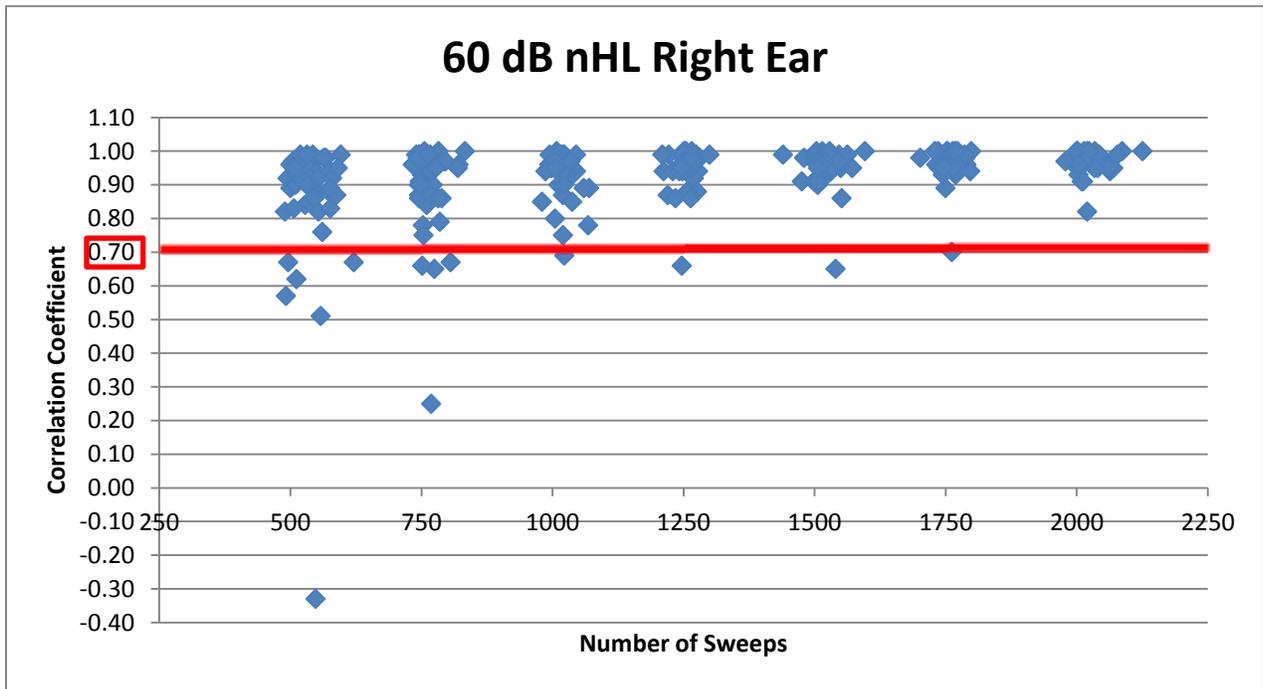
#### *Example waveform tracings for a newborn hearing screening in the left ear.*

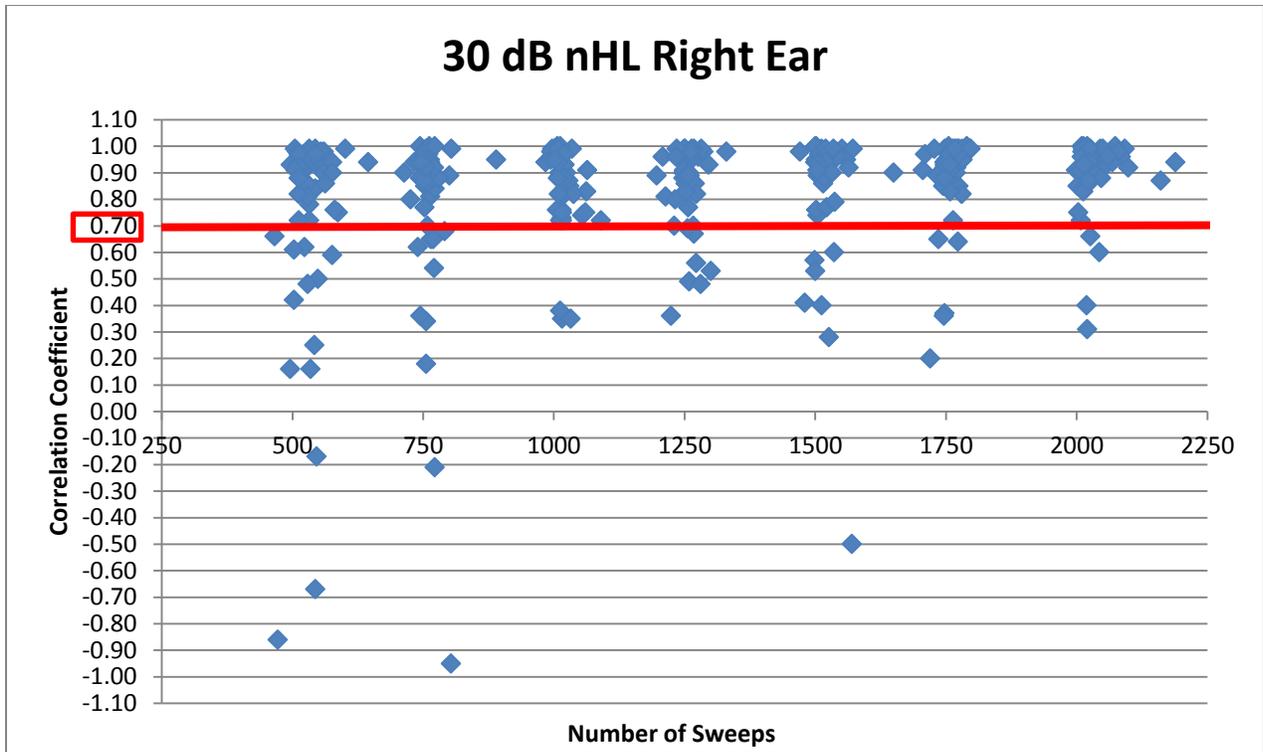
1. Top 4 tracings: 60 dB nHL intensity level. Top tracing is the combined tracing of waveforms A and B below it. The statistical start (SS) is on the peak and statistical end (SE) is on the trough of Wave V. The correlation coefficient compares the repeatability of tracings A and B between the SS and SE. The correlation coefficient for this tracing was 0.99 at 1568 equivalent sweeps. The last tracing is the difference between tracings A and B. This shows the noise floor.

2. Bottom 3 tracings: 30 dB nHL intensity level with the combined tracing of waveforms A and B and waveforms A and B displayed below it. SS and SE is also marked. The correlation coefficient was 0.90 at 2028 equivalent sweeps.

3. The yellow markings are the Boys Town Norms for a newborn that is 35-36 weeks corrected gestation for 60 dB nHL and 30 dB nHL click stimulus.

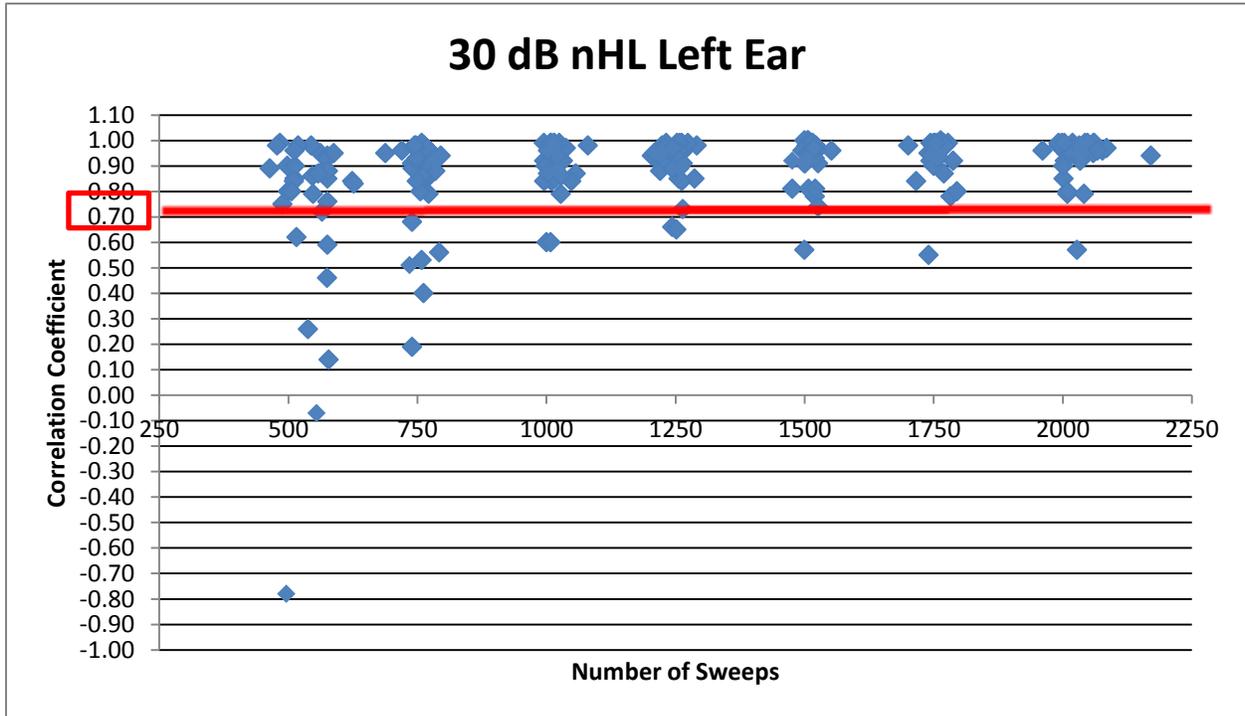
Appendix B





Scatter plots of the correlation coefficient by number of sweeps collected for all right ears tested at 60 dB nHL and 30 dB nHL. The correlation coefficient cutoff used for determination of waveform repeatability is marked on the graph (0.7).

Appendix C



Scatter plots of correlation coefficient by number of sweeps collected for all left ears tested at 60 dB nHL and 30 dB nHL. The correlation coefficient cutoff used for determination of waveform repeatability is marked on the graph (0.7).