Effects of Subject Activity on the Auditory Brainstem Response Measured with Two Different Recording Instruments

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ABSTRACT

The purpose of this study was to compare ABR recordings from the same subjects using both the Vivosonic and Bio-Logic AEP units to assess which unit is more reliable under different states of subject activity. The different subject activities were relaxed and calm, and sucking on a pacifier. Ten adult left ears with normal hearing were used in this study. To investigate the effects, a 2 x 2 x 2 analyses of variance (ANOVA) was performed using the AEP units (Biologic, Vivosonic), Pacifier (Yes, No), and level (60 dB, 30 dB) as fixed factors. The dependent variables assessed were wave V latencies, wave V correlations, and wave V apmlitudes. Results from this study revealed no significant difference between AEP units and the ABR variables compared in this study, with the exception that the Vivosonic produces better correlations than the Biologic AEP unit.

INTRODUCTION

The Auditory Brainstem Response (ABR) is a noninvasive auditory electrophysiological measurement used in newborn screenings for hearing loss and assessing brainstem function in neurological disorders. "ABRs have become widely accepted as a valuable test by a variety of professionals, such as audiologists, otolaryngologists, otologists, neurologists, pediatricians, and neonatologists"(Integrity V500 Users Manual 5.4). The ABR is a group of electrical potentials recorded from the scalp via surface electrodes and represents the electrical activity of neural elements as they travel through the auditory brainstem in response to sound (Don, 2007). It is generally characterized by 5-7 peaks/components, which occur in the brainstem during the first 10 milliseconds following the presentation of a transient acoustic stimulus to the ear (e.g., a broadband click (BBC)). The BBC is a popular stimulus choice because it elicits a synchronous response from a large population of neurons (Ferraro and Durrant, 1994). Although, as mentioned earlier, the ABR can comprise of 7, distinct components (Waves I – VII), Waves I, III, and V have emerged as the most important ones for clinical purposes (Katz et. al, 2009).

ABRs are used clinically in adults to evaluate either the presence or the underlying cause of a hearing-related disorder. For example, waveforms are often used to identify the presence of tumors that affect hearing and balance. ABRs can also be used in intraoperative monitoring to assess the integrity of the auditory nerve during various otologic surgeries. Since the ABR is an objective measure of hearing function (meaning there is no behavioral response needed to perform the test) it also is routinely used in the evaluation of hearing status in infants and those who cannot respond reliably and/or accurately to behavioral audiological measures.

Newborn hearing screenings (NBHS) have utilized the ABR as a procedure for testing neonatal babies with complicated birth risk factors. Early Hearing Detection and Intervention (EHDI) programs are intended to identify permanent hearing loss in children by 3 months of age (Joint Committee on Infant Hearing, 2007). This task would be quite difficult to accomplish with behavioral measures of hearing, considering that infants younger than 6 months of age are not developmentally capable of providing reliable head-turn responses to sounds (Bagatto, 2010). ABRs have allowed audiologists the ability to record accurate hearing threshold levels to identify hearing loss and initiate early intervention services in newborns.

It is necessary to distinguish the use of ABRs in NBHS versus ABRs as a diagnostic procedure. The newborn hearing screening is a measure that attempts to sort out normal hearing individuals from individuals with some degree of hearing loss (Jacobson, 1990). In addition, screening protocols are developed, in part, to be relatively quick and easy to perform. The ABR screening criteria at the University of Kansas Medical Center are defined as observing a replicable wave V response to a BBC stimulus at a supra-threshold level (60 dB HL) and at a normal hearing level (30 dB HL) per ear. Diagnostic ABRs are used on adults and those infants who failed the NBHS and also on "difficult to test" adults, as well as those who are suspected of having retrocochlear disorders. These procedures may focus on the respective interwave intervals for wave I, III, and V, and/or the actual threshold of the ABR.

NBHS is typically performed in a neonatal room in a hospital; therefore environmental variables may contribute to unreliable AEP recordings. In the traditional auditory evoked machines (such as the unit manufactured by Bio-logic), physiological and non-physiological artifact, particularly low frequency electric and radio frequency noise, may distort the ABR. Myogenic or movement artifact also can affect ABR recordings. For example, muscle activity in tense patients could cause variability of the component amplitudes on repeat testing. Therefore, the degree of "cooperation" by the patients is an important factor in achieving successful recordings (McCall and Ferraro, 1991). This condition can often present difficulties when administering the ABR test to infants and young children. Ideally, the easiest way to

achieve reliable AEP recordings in babies is while they are asleep and removed from sources of electrical artifact. A common technique for audiologists to implement in an effort to keep the infant quiet and relatively motionless is to give the baby a pacifier. Once again, this solution can sometimes cause variability in the waveform on repeat testing due to muscle activity. Techniques to decrease electrical interference may include turning lights off, unplugging any unnecessary electronic equipment, grounding electrical equipment, and/or shielding the testing area. These actions are often very difficult to accommodate in a neonatal care unit.

A new AEP unit called the Vivosonic Integrity was recently developed to reduce electrical interference as well muscle/movement artifact during ABR recordings. It incorporates auditory evoked potential and otoacoustic emission technology that supposedly allows AEP testing on non-sedated patients in any clinical environment. The clinical significance of using the Vivosonic lies in reducing three factors: 1) patient risk from anesthesia, 2) testing time, and 3) the costs associated with these variables.

The Vivosonic includes wireless Bluetooth communications between the computer software (Integrity Software) and the data collecting equipment (VivoLink). This technology provides the benefit of reducing physiological and non-physiological noise resulting in fast, accurate, and clear recordings, limited mobility for the patient and the user, electrode convenience using electrode clips, shorter lead wires from the VivoLink to the electrode, and less risk of probe and electrode misconnection. The VivoLink checks the electrode contact and inter-electrode impedance, checks the wireless connection, presents the auditory stimuli to the patient, and transmits collected electrophysiological responses to the Integrity Software.

To reduce physiological and non-physiological noise, differential pre-amplifiers are used so that the signal of interest (ABR) is measured as the difference between the electric potentials recorded from two electrodes (the non-inverting/positive primary electrode and the inverting/negative/secondary electrode). A common ground electrode is used to help improve common-mode-rejection, which cancels signals (i.e., noise) that is seen in the same phase by both the non-inverting and inverting electrodes (User's Manual). The Vivosonic employs the "world's first *in-situ* audiometry pre-amplifier" called the Amplitrode that "largely reduces physiological noise and electromagnetic interferences" (User's Manual). The Amplitrode allows the amplifier to be directly mounted on the conductive pad portion of the electrode, therefore increasing the signal to noise ratio by shortening the connection between the electrode and the amplifier. In conventional AEP units, the amplifier is usually located in the computer software, resulting in an electrode-to-wire, wire-to-amplifier arrangement. Motion artifacts are reduced in the

Vivosonic due to the fact that the electrodes, the wires between electrodes, and the pre-amplifier move together and are all mounted on the patient.

The Vivosonic AEP unit uses a digital signal processing technique called the Kalman Filter to allow ABR testing in the presence of excessive noise produced my facial muscles. The Kalman Weighted filtering is an algorithm to give more weight in the ABR to responses with less myogenic artifact. When the subject moves intermittently during the test and produces myogenic artifact, the Kalman Filter will yield a result that is less contaminated by noise. When the subject is relaxed throughout the test, Kalman Filtering decreases the weighting and yields the same result as conventional averaging (Integrity V500 Users Manual 5.4).

The primary AEP unit used in the Hearing and Speech Department for both clinical testing and research studies is the Bio-Logic Nav Pro. The Vivosonic was purchased because of the supposed benefits it offers in comparison to the Bio-Logic in reducing movement and electrical artifact during ABR recordings. However, no direct comparative study between units has been conducted to verify this contention. Therefore, the purpose of this study was to compare ABR recordings from the same subjects using both the Vivosonic and Bio-Logic AEP units to assess which unit is more reliable under different states of subject activity. Namely, the ABR will be recorded using each unit while the subject is awake and calm, and also while sucking on a pacifier, just as a baby would be doing during an ABR exam in the NICU. The absolute latency of wave V, peak to trough amplitude of wave V, and correlations between wave Vs on repeat tests were used to evaluate the morphology of the ABR waveform under the different conditions described above.

METHODS

Participants

A Human Subject Committee Review protocol was submitted at the University of Kansas Medical Center and approved for this study. Subjects provided informed written consent prior to participating. Subjects for this study consisted of 10 adults ranging in age from 23 – 31 years, with normal hearing (thresholds of 25 dB HL or less) and no history of a hearing deficit or neurologic disorder. The subject's left ear was used for this study. The student investigator contacted subjects via email, telephone, or face-to-face communication, although the majority of subjects were fellow classmates.

Testing Procedure

ABRs were recorded using the Bio-logic and the Vivosonic Integrity AEP units in a sound treated booth located in the KUMC Hearing and Speech Department's Auditory Evoked Potential Laboratory/Clinic. The subject sat in a comfortable, recliner chair. Otoscopy inspection was performed to ensure that there were no obstructions in the ear canal. The electrophysiological response to broad band click (100 microsecond electrical pulse) was measured via disposable surface electrodes that contain a sponge-like foam parameter infused with conductive gel, connected to an adhesive back allowing for good contact with clean skin (no dirt, make-up, oil, ect). Prior to the application of the electrodes, alcohol and a mild, abrasive jelly were used to cleanse the subject's forehead and skin over both mastoids to insure good contact with the electrodes. The impedance between the skin and electrode were assessed, and maintained under 5000 ohms. If the impedances were higher, non-physiological noise would have been higher, signal to noise ratio would have been lower, and signal recording and detection would have taken longer. Electrode configurations for both AEP units were set up as follows: (+) non-inverting electrode - high forehead; (-) inverting electrode – mastoid on the left ear; common/ground electrode – mastoid on the right ear. The VivoLink for the Vivosonic AEP unit was placed on the subject's chest during the recordings.

The stimulus was delivered by a tubal insert earphone connected to the left ear canal via a sound delivery tube with a foam ear tip. The insert transducers increase the sound propagation time, therefore adding time to the onset of the stimulus after traveling through the tube by approximately 0.80 ms (Ferraro and Durrant, 1994). The initial recording was measured at 60 dB nHL. If a well-defined ABR was present, stimuli were lowered to 30 dB nHL to replicate a NBHS ABR procedure. Each participant was tested with both AEP units while lying quietly and also while sucking on a pacifier. For the pacifier recordings, the participant was told to suck on the pacifier as they think a baby would. The order of AEP units and quiet/pacifier state was random for each patient. Testing 60 dB nHL first was constant in all states. All procedures are noninvasive and painless, and stimuli were delivered well below levels that would be injurious to hearing.

The morphology of the ABR was assessed using the absolute latency of wave V, the amplitude of wave V, and the correlation coefficients of wave V on repeated testing. Absolute latency represents the time of occurrence of the wave V peak post-stimulus onset (measured in milliseconds). Wave V amplitude is measured as the peak-to-following trough difference in microvolts of this component. Wave V correlation is measured as the peak-to-following trough difference between 2 repeatable waveforms.

Stimuli

BBC were presented in a condensation polarity rate of 37.7 per second. During a condensation click, the initial displacement of the cochlear partition is towards to scala tympani (down) as the stapes moves inwards. If the rate were slower, collection time would be longer, while a faster rate could cause an adaptation of the response. The rate also should not be an integer submultiple of 60 to avoid 60 Hz cycle interference. The neonatal ABR screenings generally uses a rate from 30-35 Hz, which minimizes adaptation while decreasing testing time and avoiding 60 Hz artifact (Ferraro and Durrant, 1994).

The number of stimuli used on the Vivosonic was 2,000 and the number of stimuli for the Bio-Logic was only 1,000. This difference is due to the automatic combination of 2 different waveforms that the Vivosonic performs. In order for this to be an equal evaluation, 1,000 sweeps were repeated in each state, at each level on the Bio-Logic unit, whereas 2,000 sweeps were performed at each level, without a repeat, on the Vivosonic.

Analog filtering is used to improve the signal to noise ratio. The low frequency cut-off filter used for this experiment is 30 Hz allowing some elimination of low-frequency electrical and electrophysiologic noise. The high frequency cut-off filter used is 1500 Hz so that high frequency noise is reduced. Signal averaging is processed differently in the 2 AEP units. Conventional signal averaging algorithms were used in the Bio-Logic AEP unit, whereas the Kalman Weighted averaging was used in the Vivosonic AEP unit. These are used to improve the signal to noise ratio by summing the signal and background signal over time and extracting the signal from noise.

Artifact rejection is turned on to prevent random and spurious voltage changes during the recording. An entire sweep that is contaminated with spurious voltage changes is excluded from the signal averaging. The Vivosonic records artifact rejection values under "Equivalent Sweeps," whereas the Bio-Logic system records their values under "artifacts."

To investigate the effects a 2 x 2 x 2 analyses of variance (ANOVA) was performed using the AEP units (Biologic, Vivosonic), Pacifier (Yes, No), and level (60 dB, 30 dB) as fixed factors. The dependent variables in this experiment are amplitude, correlation coefficient, and wave V latency.

RESULTS

Wave V Latency

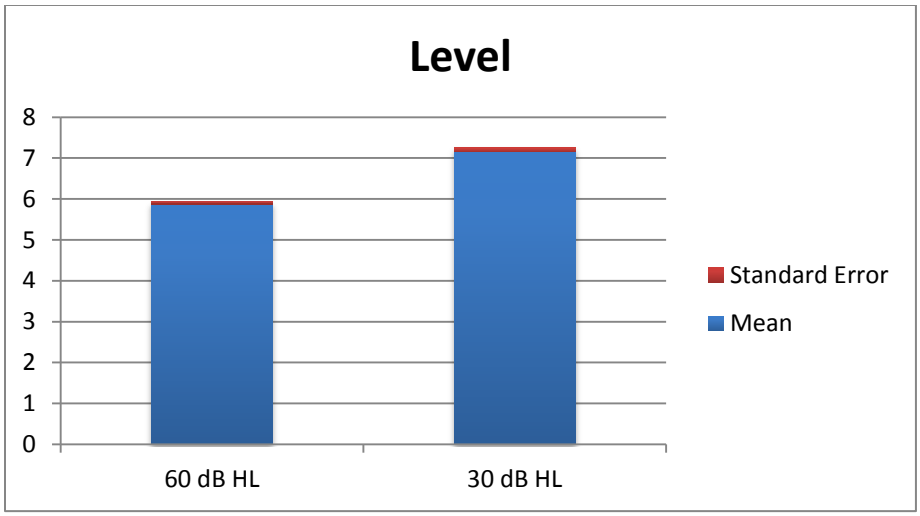
Descriptive Statistics

	Mean	Std. Deviation	N
Biologic/Pacifier/60 dB HL	5.9050	.40275	10
Biologic/Pacifier/30 dB HL	7.1310	.52184	10
Biologic/No Pacifier/60 dB HL	5.8630	.26642	10
Biologic/No Pacifier/30 dB HL	7.1320	.38490	10
Vivosonic/Pacifier/60 dB HL	5.8170	.20683	10
Vivosonic/Pacifier/30 dB HL	7.1920	.45350	10
Vivosonic/No Pacifier/60 dB HL	5.8410	.26831	10
Vivosonic/No Pacififer/30 dB HL	7.1520	.34295	10

were of the Wave a 3 The wave V latencies measured on the repeated averaged waveforms at the peak fifth wave. The descriptive statistics are provided in table 1. V latencies were analyzed using factor repeated measure ANOVA.

Table 1. Descriptive statistics. The unit (Biologic or Vivosonic) is listed first, whether or not the pacifier was being tested is listed second, and then the level at which testing occurred (60 dB HL or 30 dB HL).

The statistical analysis for wave V latency revealed that there were no statistically significant differences between which unit was used (p=.916) and if the pacifier was used or not (p=.787), although it did reveal a difference in wave V latencies depending on what level was tested (p=.000).



Graph 1. Wave V latency mean and standard error values at 60 dB HL and 30 dB HL.

There was not a wave V latency interaction between unit and pacifier (p=.888), between unit and level (p=.332), or between pacifier and level (p=.910). The 3 way repeated measure between unit, pacifier, and level revealed no significant interactions (p=.607).

Wave V Correlation

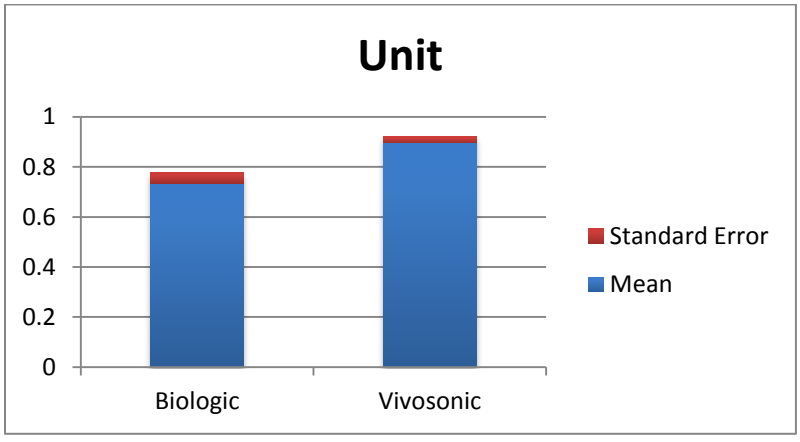
Wave V correlations were measured on the waveforms by setting cursor 1 at the peak of the fifth wave and cursor 2 at the trough of the fifth wave. The Vivosonic correlations were measured on the combined repeated waveforms and the Biologic correlations were measured on the two repeated waveforms due to the differences in software calculations. The descriptive statistics are provided in table 2. Wave V correlations were analyzed using a 3 factor repeated measure ANOVA.

Descriptive Statistics

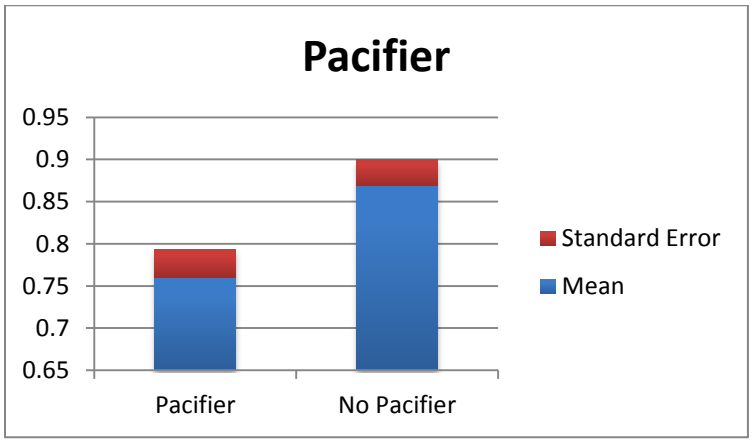
	Mean	Std. Deviation	N
Biologic/Pacifier/60 dB HL	.86000	.202313	10
Biologic/Pacifier/30 dB HL	.52270	.247734	10
Biologic/No Pacifier/60 dB HL	.91150	.079188	10
Biologic/No Pacifier/30 dB HL	.63750	.373129	10
Vivosonic/Pacifier/60 dB HL	.94000	.060919	10
Vivosonic/Pacifier/30 dB HL	.71540	.322694	10
Vivosonic/No Pacifier/60 dB HL	.98500	.021213	10
Vivosonic/No Pacififer/30 dB HL	.94300	.067338	10

Table 2. Descriptive statistics. The unit (Biologic or Vivosonic) is listed first, whether or not the pacifier was being tested is listed second, and then the level at which testing occurred (60 dB HL or 30 dB HL).

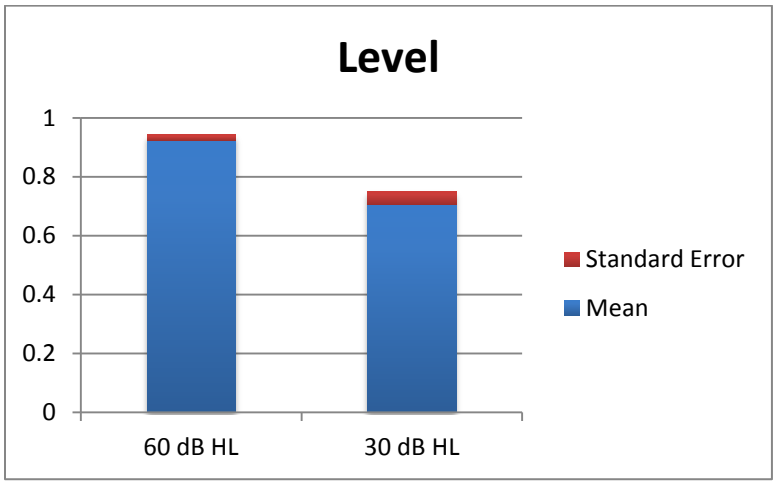
The repeated measure analysis was statistically significant for the wave V correlations depending on the unit used (p=.008), whether a pacifier was used or not (p=.020), and which level was used (p=.001).



Graph 2. Wave V correlation mean and standard error on the Biologic and Vivosonic.

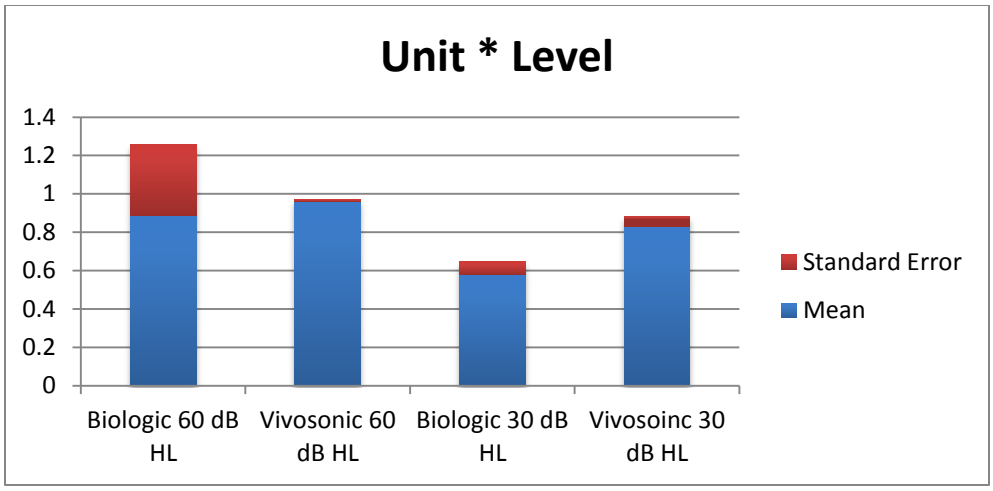


Graph 3. Wave V correlation means and standard error with and without a pacifier.



Graph 4. Wave V correlation means and standard error at 60 dB HL and 30 dB HL.

There were no wave V correlation interactions between the unit and pacifier (p=.652), the unit and level (p=.213), and the unit, pacifier, and level (p=.571). However, there was a statistically significant interaction (p=.037) between which unit was used and at what level. Graph 4 provides the correlation means and standard errors under the unit and level conditions. Figure 1 illustrates the relationship.



Graph 5. Wave V correlation means and standard error on both units at 60 dB HL and 30 dB HL.

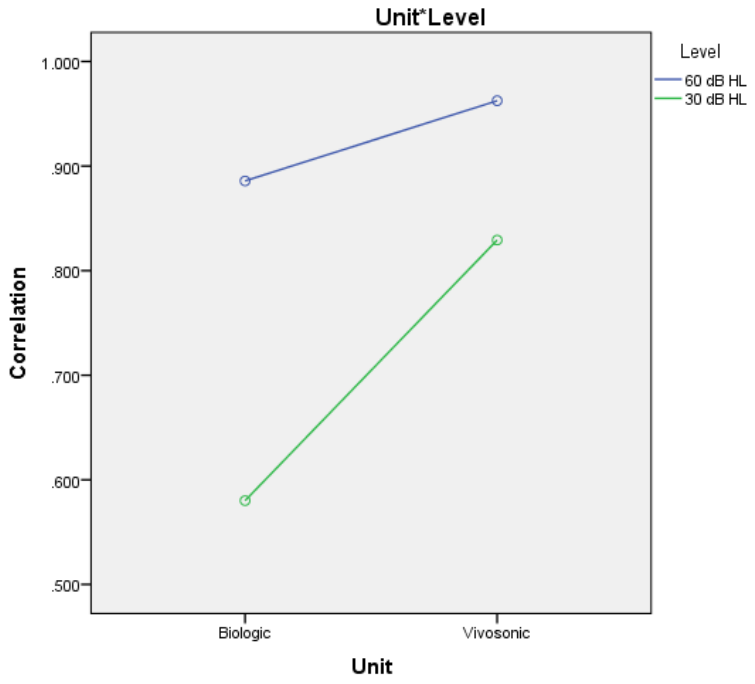


Figure 1 illustrates the relationship depending on unit and level.

The statistical significance represented above was analyzed using a t-test to examine which factors were significant. The t-test revealed a significant interaction between the Biologic at 60 dB HL and the Biologic at 30 dB HL ($p<.05$, $p=.001$).

Wave V Amplitude

The wave V amplitudes were measured on the repeated averaged waveforms by setting cursor 1 at the peak of the fifth wave and cursor 2 at the trough of the fifth wave. The descriptive statistics are provided in table 3. Wave V amplitudes were analyzed using a 3 factor repeated measure ANOVA.

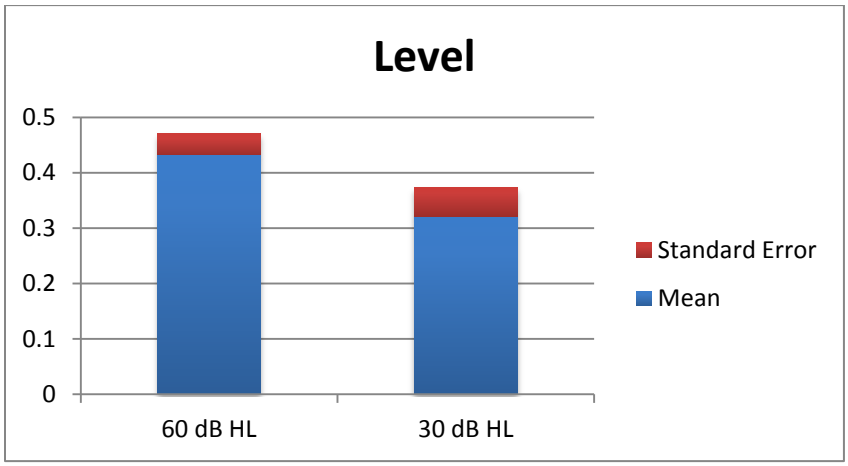
Descriptive Statistics

	Mean	Std. Deviation	N
Biologic/Pacifier/60 dB HL	.3780	.14861	10
Biologic/Pacifier/30 dB HL	.2210	.15081	10
Biologic/No Pacifier/60 dB HL	.4660	.21293	10
Biologic/No Pacifier/30 dB HL	.3200	.21566	10
Vivosonic/Pacifier/60 dB HL	.4820	.18879	10
Vivosonic/Pacifier/30 dB HL	.3967	.25626	10
Vivosonic/No Pacifier/60 dB HL	.4020	.15259	10
Vivosonic/No Pacififer/30 dB HL	.3470	.20006	10

Table 3. Descriptive statistics. The unit (Biologic or Vivosonic) is listed first, whether or not the pacifier was being tested is listed second, and then the level at which testing occurred (60 dB HL or 30 dB HL).

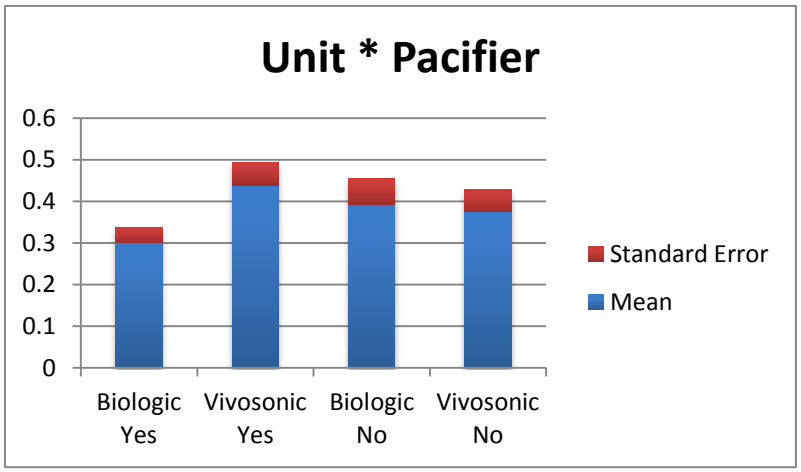
The statistical analysis for wave V amplitude revealed that there were no statistically significant interactions between which unit was used ($p=.211$) and if the pacifier was used or not ($p=.725$), although

it did reveal a difference in wave V latencies depending on what level was tested (p=.023). Graph 6 represents the significance.



Graph 6. Wave V amplitude means and standard error values at 60 dB HL and 30 dB HL.

There were no wave V amplitude interactions between the unit and level (p=.118), the level and pacifier (p=.679), and the unit, pacifier, and level (p=.889). However, there was a statistically significant interaction (p=.021) between which unit was used and if a pacifier was used or not. Graph 7 represents that amplitude means under each unit and with/without the pacifier. Figure 2 illustrates the relationship.



Graph 7. Wave V amplitude means and standard errors on each unit, with (Yes) and without (NO) a pacifier.

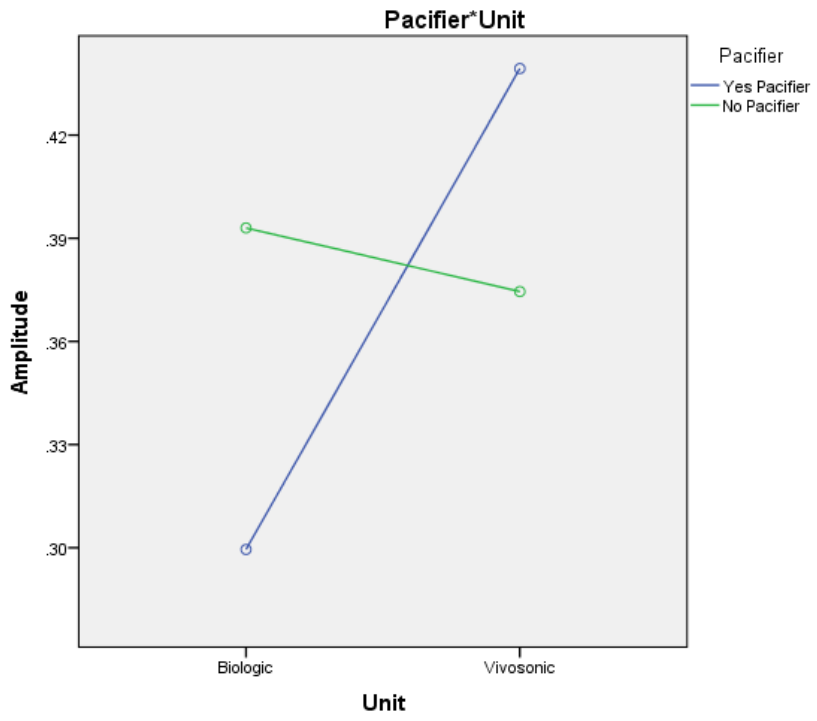


Figure 2 illustrates the relationship between the combination of unit and whether or not a pacifier was used.

The statistical significance represented above was analyzed using a t-test to examine which factors were significant. The t-test revealed significant interactions between the Biologic with and without the pacifier ($p<.05$, $p=.024$), and the Biologic with the pacifier compared to the Vivosonic with the pacifier ($p<.05$, $p=.009$).

DISCUSSION

During the study, three participants did not have a wave V on one of the conditions. In order to supplement for the missing wave V, the mean of all of the other subjects was used for that subject's value. An analysis was performed without those patients as well, although the exemption did not change the results of the study. An independent observer who was unfamiliar with subject state of activity verified waveforms.

Wave V Latency

The factor analysis on the level of stimulus revealed that the wave V latency was statistically significant between 60 dB HL and 30 dB HL (Graph 1). In general, the level difference is expected and for this particular study, we were not concerned about the level difference alone. No other conditions were statistically significant under the wave V latency variable, meaning that there were no wave V latency differences depending on which unit was used and whether or not a pacifier was used.

Wave V Correlation

The factor analysis on the wave V correlation was statistically significant between the factors alone. The Kalman filtering on the Vivosonic was able to cancel out the noise and produce a better correlation than the Bio-Logic. The correlations were better without a pacifier because there was not extra noise attributing to the response compared to when the subject was sucking on a pacifier. 60 dB HL had better correlations than the 30 dB HL because there is a stronger, more robust response at a higher level. The different units resulted in statistically different correlation values depending on which level was tested. This was significant because the Biologic had a better correlation at 60 dB HL compared to 30 dB HL, but the Vivosonic correlations at the different levels were not statistically significant.

Wave V Amplitudes

The factor analysis on the stimulus level revealed that the wave V amplitude was significantly larger at 60 dB HL than at 30 dB HL, which is to be expected. The factor analyses also revealed a statistically significant interaction between which unit was used and whether or not a pacifier was used. This was significant because the Biologic had a greater response without the pacifier than with, although the Vivosonic was not affected. While the subject was sucked on the pacifier, more filtering was happening, which means more rejections and less actual responses were recorded. Another reason for why this interaction was significant was because there was a statistically significant difference between the amplitudes on the Bio-Logic with the pacifier compared the Vivosonic with a pacifier. This finding is a result of the Kalman filtering compared to the traditional algorithms performed by the Biologic. The Kalman filtering is able to filter out the signal to noise ratio better than the traditional algorithms, resulting in a greater response on the Vivosonic.

CONCLUSIONS

The focus of this study was to compare ABR recordings from the same subjects using both the Vivosonic and Bio-Logic AEP units to assess which unit is more reliable under different conditions of subject activity. This study has revealed that wave V latency is not affected by whether or not a pacifier is used and/or which AEP unit is used, which is the most important component for ABR waveform analyses. Wave V correlations were different depending on what level was tested and whether a pacifier was used or not, although the AEP unit did not affect the correlations.

The pacifier factor within the study did not change the correlations or latencies, although it did change the amplitudes. Wave V amplitudes were greater with a pacifier on the Vivosonic compared to the Biologic with a pacifier. Amplitudes are not used as diagnostic values in ABR testing, although larger amplitudes can result in more accurately identifying wave V in a waveform.

In conclusion, there is not a significant difference between AEP units and the ABR variables compared in this study, with the exception that the Vivosonic producing better correlations than the Biologic. Additional research is warranted to evaluate the electrical interference factor in different arousal states. Our observation was that testing with the Vivosonic was quicker than the Biologic, so if time is a concern the Vivosonic may be a preferable instrument. Otherwise, the units performed similarly on each condition.

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