Artifactual Responses in Auditory Steady State Responses Recorded Using Phase Coherence Method

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Abstract

It has been reported that artifacts at high stimulus levels contaminated auditory steady state responses (ASSR) when weighted averaging method was used to detect the responses. A few commercially available instruments use phase coherence method to detect the presence of ASSR. The current study investigated the presence of artifactual responses in ASSR when a phase coherence method is used. ASSR was recorded in fifteen adult participants with profound hearing loss, who did not show any behavioural responses. The upper limits of stimulation for obtaining artifact free ASSR, using supra aural headphones, insert earphones and a bone vibrator were determined. Analysis of the results revealed that the upper limit of stimulation for obtaining artifcat free ASSR is 95 dBHL for supra aural headphones, 105 dBHL for insert ear-phones and 50 dBHL for a bone vibrator. Phase analysis of the artifacts suggested that artifacts were either due to non-auditory physiological responses and/or electromagnetic aliasing artefacts
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Key words: ASSR, Air conduction, Bone conduction, Phase Coherence, Artifacts

The human auditory steady state responses (ASSR) can provide rapid and objective assessment of auditory thresholds (Picton, John, Dimitrijevic & Prucell, 2003). ASSR is recorded for sinusoids that are either amplitude, frequency or mixed modulated. As continuous modulated stimuli are used for recording ASSR, stimuli can be presented at intensities higher than that normally used for auditory brainstem responses (> 95 dBHL) and this in turn helps in differentiating severe to profound hearing loss (Rance, Dowell, Rickards, Beer & Clark, 1998; Rance, Rickards, Cohen, Burton & Clark, 1993; Swanepoel, Hugo & Roode, 2004). However, Gorga et al. (2004) initially questioned the reliability of ASSR in predicting hearing thresholds in individuals with severe to profound hearing loss. They observed the presence of artifactual ASSRs at higher levels (> 95 dBHL) in ten individuals with profound hearing loss, who did not show any behavioural responses to modulated stimuli even at the upper limits of the ASSR system. Small and Stapells (2004) also reported of the presence of artifactual responses in 55% of their subjects for air conduction stimuli and 80% of their subjects for bone conduction stimuli.

Investigators have hypothesized that electromagnetic stimulus artifacts do not interfere with the responses even when ASSR is recorded for very high levels of stimuli, as ASSRs are elicited by the envelope of the stimuli rather than by the carrier. Picton and John (2004) have reasoned out that, "**aliasing**" error cause the occurrence of artifacts at higher levels in ASSR. Aliasing occurs when a signal is sampled at a rate lower than twice its frequency as such a signal will have energy at a frequency equal to absolute frequency and its closest multiple integer of sampling rate (Picton, Hink, Perez-Abalo, Linden & Wiens,1984). Small and Stapells (2004) explained that the frequency of the aliasing error is equal to the difference between the closest integer multiple of sampling frequency and input frequency. For example a 1000 Hz tone that is amplitude modulated at 80 Hz would have energy at 920, 1000, 1080 Hz. If 920 Hz is present in the EEG being digitized at 500 Hz, the alias frequency would be 1000 Hz-920 Hz = 80 Hz which is exactly the same as the modulation rate for this 1000 Hz carrier frequency. Figure 1 shows the graphical representation of an example of aliasing error.

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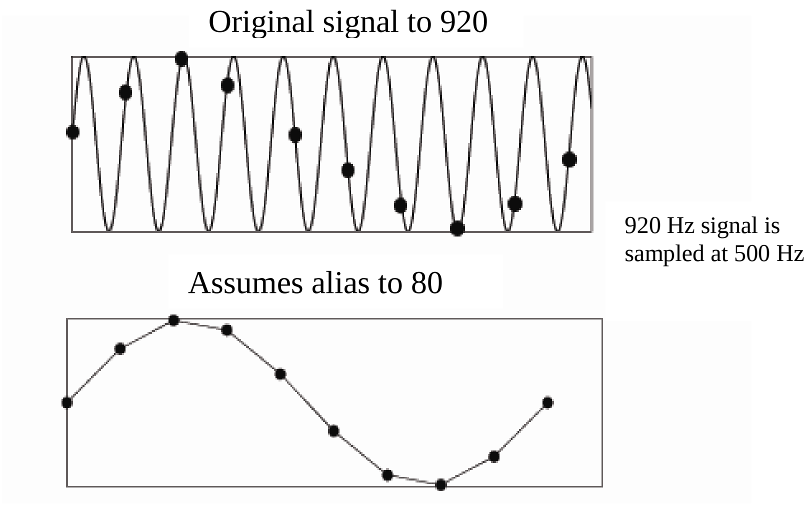

Figure 1- Graphical representation of aliasing error

The studies that have reported artifacts in ASSR have recorded ASSR using instruments which use weighted averaging method. These instruments analyse the amplitude of the responses at modulation frequency with respect to side bands using Fast Fourier Transform (FFT). Hence there are chances that the aliasing artifacts can be sensed by the instrument as a response. One another method used to identify the responses in ASSR is phase coherence. If the phase of artifactual response is different across the averages, there may not be any artifact when ASSR is recorded using phase coherence method. The current study was designed to investigate if artifacts occur while recording ASSR in an instrument which uses a phase coherence method to detect responses and if it occurs to determine the upper limits at which artifact free ASSR could be recorded using supraaural headphones, insert phones and a bone vibrator.

Method

Participants

Fifteen participants with profound hearing loss, ranging in age from 18-30 years participated in the present study. Only those ears in which there was no behavioural response to modulated stimuli even at the upper-limits of the ASSR instrument at octave frequencies from 500 Hz to 4000 Hz were considered for the study. A total of 24 ears met these criteria (12 for air conduction and 12 for bone conduction) and six ears were not considered as they had minimal residual hearing.

Instrumentation

A calibrated two channel diagnostic audiometer with TDH 39 head phones housed in supra aural ear cushions and a bone vibrator, Radio ear B-71 was used to carry out pure-tone audiometry. GSI- Audera ASSR, Version-2 system was used to estimate the behavioural thresholds for modulated signal as well as to record ASSR using supra aural head phones (TDH-49), insert ear phone (ER-3A) and bone vibrator (Radio ear B-71).

Procedure

Pure-tone thresholds were obtained using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959), across octave frequencies from 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction stimuli. Behavioural thresholds were also assessed for mixed modulated stimuli used for recording ASSR, across octave frequencies from 500 to 4000 Hz.

ASSR was recorded for the participants who did not show any behavioural thresholds for mixed modulated stimuli even at the upper limits of the ASSR system. While recording ASSR, the participants were seated comfortably on a chair. Silver chloride (Agcl) electrodes were placed using conventional three-electrode placement (M_1, M_2, F_z), after cleaning the electrode site with skin preparing paste. It was ensured that impedance at each electrode site was less than 5 kΩ and inter electrode impedance was less than 2 kΩ. The participants were asked to relax and sleep while recording ASSR. While recording ASSR for bone conducted stimuli M_1, M_2, and Cz electrode placements were used and the bone vibrator was placed on the forehead.

ASSR measurements were performed using high modulation frequency of 74, 81, 88, 95 Hz for 500, 1000, 2000 and 4000 Hz respectively. The raw EEG was recorded and pre-amplified by 1lakh time and sampled at 500 Hz A/D conversion rate. The sampled data was filtered using a band pass filter of 30-300 Hz. Phase and amplitude of the responses were obtained after performing FFT. Phase coherence was determined using the statistical software incorporated in the instrument. Based on the “phase coherence” the instrument determined the presence or absence of a response automatically. The ASSR threshold was determined using a bracketing method and the minimum intensity at which a phase locked response was present was considered as the ASSR threshold. The recordings were replicated to ensure the presence of a response. The phase delay for the lowest stimulus level at which responses were present was considered for the analysis.

Results

It was observed that phase locked responses (atifacts) were present in all the 12 ears for stimuli presented through both the air conduction transducers where as for stimuli presented through a bone vibrator only 11 ears had artifacts. The lowest intensity at which artifactual responses occurred was 95 dBHL for the supra-aural headphones, 100 dBHL for the insert earphones and 50 dBHL for the bone vibrator. As shown in the Fig-2, there was higher probability of occurrence of artifactual responses for stimuli presented through supra aural headphones than insert earphones at 1 kHz and 2 kHz. The occurrence of artifacts was less for bone conducted stimuli when compared air conducted stimuli.

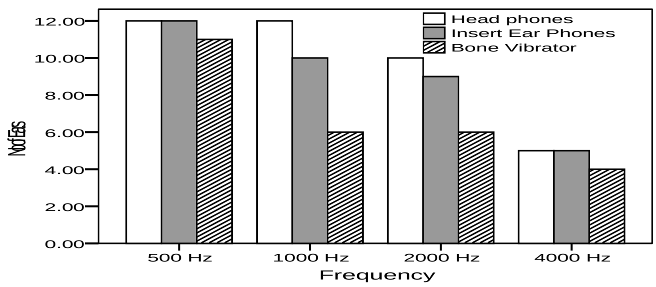

Figure 2. Number of ears having artifactual responses for different transducers at different frequencies.

Fig-3 shows the lowest intensity at which artifactual responses were observed across frequencies for different transducers. It was observed that the artifactual responses were observed below 110 dBHL for stimuli presented through supra-aural head phones and insert earphones and below 60 dBHL for stimuli presented through the bone vibrator for low frequencies, where as for high frequencies, artifacts were observed only at high stimulus level.

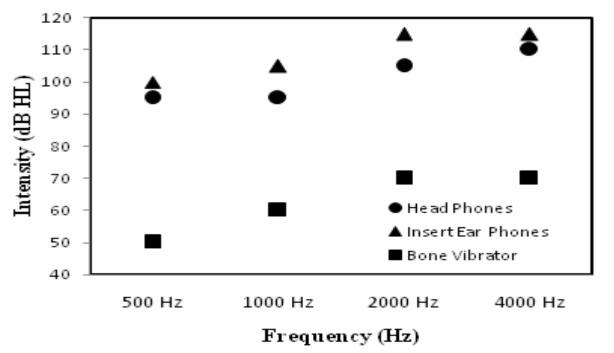

Figure 3. Lowest intensity at which artifacts occurred for different transducers and frequencies.

For the ears in which artefacts were present, phase delay was calculated. The general inspection of the data revealed that ASSR recorded through supra aural headphones and insert earphones, the phase variability was more for ASSRs recorded across subjects for intensities above 110 dBHL. Whereas phase delay of the responses was with in 90^0 for the responses recorded for intensities below 110 dBHL. The phases of the responses were almost similar for ASSRs recorded through supra aural head phones and insert earphones. So the data from the two transducers were combined for further analysis. Fig-4 compares the phase of the responses when the intensity was above 110 dBHL and when it was below 110 dBHL for 500 Hz and 1000 Hz stimuli. Data for 4000 Hz and 2000 Hz were not considered as less number of ears had artifactual responses at low stimulus level. It can be observed that for responses recorded below 110 dBHL, the phase delay of the responses for a majority of the data was in the same quadrant, whereas at intensities above 110dBHL stimulus level the phase delay was not same across the participants. The data also indicates that at low stimulus levels phase delay is in the range of 0^0 to 90^0. However a few ears had phase delay which was distributed across the quadrants.

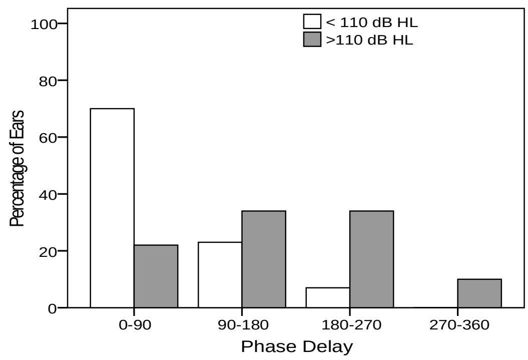

Figure 4. Phase delay of the artifactual responses below and above 110dB for head phones and insert ear phones.

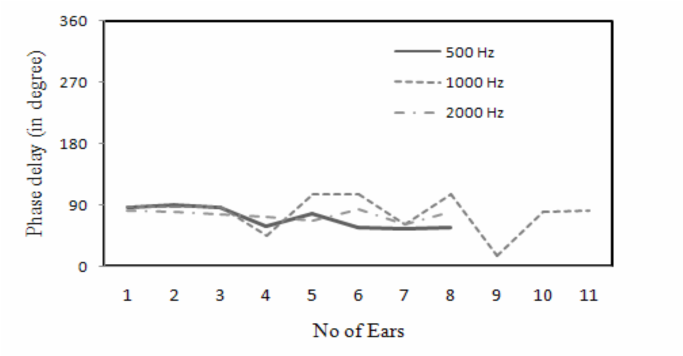

Figure 5. Phase delay of the artifactual responses below for bonevibrator.

Phase delay of responses for stimuli presented through the bone vibrator was recorded for those frequencies where responses were present. Fig-5 depicts the phase delay of the responses for frequencies 500 Hz and 1000 Hz and 2000 Hz. It can be observed from the figure that phase delays for most of the data were in same quadrant that is 0^0 to 90^0. Data for 4000Hz was not considered as less number of subjects had artifactual responses at a low stimulus level for 4000 Hz.

Discussion

Results of the present study indicate that artifactual responses were present for stimulus levels above 95 dBHL for supraaural head phones and insert ear phones when ASSR was analyzed using phase coherence method. For stimuli presented through a bone vibrator, artifacts occurred when the intensity of the stimuli was above 50 dBHL. The presence of artifacts was less for bone conducted stimuli compared to air conducted stimuli probably because the bone vibrator was away from the electrodes. The occurrence of artifactual responses was more for supra-aural headphones when compared to insert earphones. This may be probably because the diaphragm of the insert earphone was away from the electrodes, and hence reduced the strength of the electromagnetic field that reached the electrodes in comparison to that of supra aural earphones.

Artifacts occurred more for low frequency stimuli when compared to high frequency stimuli. For high frequencies artifacts were observed only at high intensities. Earlier investigators (Small & Stapells, 2004; Gorga et al., 2004) have also reported that artifacts reduced as the frequency of the stimuli increased. Small and Stapells (2004) attribute this to less energy required to derive the oscillator at high frequencies when compared to low frequencies, which in turn produces less electromagnetic field at high frequencies. This reduces the amplitude of the artifactual responses and hence probably artifacts were present only at very high intensities for high frequencies.

Two possible explanations have been attributed for the presence of artifactual responses at low frequencies, one due to aliasing of electromagnetic stimulus energy and non-auditory physiological responses (Small & Stapells, 2004; Picton & John, 2004). To investigate the probable origin of artifacts seen in present study, the phase delay of ASSR responses were analyzed. The results of the phase delay analysis suggested that phase delay was variable at intensities above 110 dBHL at all the frequencies. Investigators have reported in the literature that phase delay is replicable and follows a specific trend in normal individuals. Low carrier frequencies have higher phase delay than high frequencies (John & Picton, 2000). The variability of the phase delay of the responses across all frequencies was probably due to aliasing of electromagnetic stimulus energy, where the phase becomes unpredictable across recordings due to the variability in strength and phase of electromagnetic stimulus energy. Phase was further reported to be modified by A/D conversion, filtering and amplification of electromagnetic stimulus energy (Picton & John 2004). So, artifactual responses in the present study may be due to aliasing of electromagnetic stimulus energy at high intensities (> 110 dBHL) in majority of the ears.

Phase delay of the responses were in the same quadrant (0˚ to 90˚) for low stimulus levels in 60-70% of the ears for 500 Hz and 20% of the ears for 1000Hz stimuli. Even for the bone conducted stimuli, the phase delay of the responses was with in 90^o for a majority of the ears. The predictability of the phase delay suggests that it may not be due to electromagnetic artifact. Latency of these responses can be estimated using formula $P/360 \times Fm$, where P is phase delay and Fm refers to modulation frequency (John & Picton, 2000). The latency of the responses observed in the present study was in the range of three-five milli seconds (3-5msec). Similar results were reported by Small and Stapells (2004) for bone conducted stimuli. Probably they did not observe these results for air conduction stimuli because they did not place the ear tip of the insert earphone in the ear canal while recording ASSR for air conduction stimuli. The latency of the artifactual responses observed in the present study is comparable with the latency of N3 reported by Nong, Ura, Owa and Noda (2000). Therefore, these artifactual responses may be of physiological origin and may be similar to the negative peak (N3) seen at 3 msec in individuals with profound hearing loss. It has been reported that the N3 is generated in brainstem vestibular nuclei by activating the saccule (Nong, Ura, Owa & Noda, 2000).

Conclusion

It can be concluded from the present study that artifactual responses occur above 95 dBHL for supra aural headphones, 105 dBHL for insert earphones and 50 dBHL for bone vibrator. The artifacts observed may be of due to non-auditory physiological responses at intensities below 110 dBHL and due to electromagnetic artifacts at intensities above 110 dBHL for air conduction transducers. The important clinical implication of the current study is that, the audiologists should be cautious while interpreting the ASSR at high intensities.

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