Reduction of Stimulus Artifacts in ASSR: An Investigation of a Stimulus Approach

Arivudai Nambi P & C S Vanaja*

Abstract

Auditory steady state responses at high stimulus levels were contaminated by artifacts when weighted averaging method as well as phase coherence method is used detect responses. The current study aimed to determine the upper limit for artifact free ASSR for stimuli presented through headphone and bone vibrator. The current study also investigated whether artifacts can be avoided by changing the carrier frequency in such a way that they are not integer multiple of sampling frequency. ASSR was recorded in 30 individuals with profound hearing loss who did not show behavioural responses even at the upper limit of ASSR system. The results revealed that the upper limit for artifact free ASSR measurement for head phone is 90 dB HL and for bone vibrator is 50 dB HL. Changing the carrier frequency enhanced the dynamic range for artifact free ASSR measurement obtained through headphone and bone vibrator.

Introduction

Auditory steady state response (ASSR) is one of the objective methods for estimation of behavioural thresholds (Cone-wesson et al., 2002; Aoyagi et al., 1994; Luts & Wouter, 2005). ASSR examines the response for sinusoids that are amplitude, frequency or mixed modulated stimuli. Since stimuli used for ASSR recording is continuous and modulated in nature it is possible to present a stimuli upto 120 dB HL also. This feature allows the ASSR to assess the hearing threshold levels greater than 80 dB HL and it differentiates severe to profound hearing loss (Rance et al., 1998; Rance et al., 1993; Swanepoel, Hugo & Roode, 2004). Gorga et al. (2004) initially pointed out the presence of artifactual ASSR at higher levels (>95 dBHL) in individuals with profound hearing loss who did not show any behavioral responses to modulated stimuli even at the upper limits of ASSR system. The presence of these artifacts was also supported by other investigators (Small & Stapells, 2004; Picton & John, 2004). Presence of these artifacts at higher level might limit the ASSR's application to differentiate between severe and profound hearing loss. Picton and John (2004) have reasoned out that "aliasing" error cause the occurrence of artifacts at higher levels. Aliasing occurs when signal is sampled at a rate lower than twice its frequency. Then the signal is seen at a frequency equal to absolute frequency and its closest multiple integer of sampling rate. The sampling rate used in the ASSRs is

* Professor of Audiology, School of Audiology and Speech Language Pathology, Bharathiya Vidya Peet University, Katra-Dhanakawadi, Pune, India. e-mail: csvanaja@rediffmail.com

designed for the efficient analysis of the responses at the frequencies of modulation. Small and Stapells (2004) explained that frequency of the aliasing error which occur in ASSR can be predicted by the formula,

Alias frequency = Closest integer multiple of sampling frequency- Input frequency

For example a 500 Hz tone that is amplitude modulated at 80 Hz would have energy at 420, 500, 580 Hz. If this energy is present in the EEG being digitized at 500 Hz an alias frequency would be 500Hz-420Hz = 80Hz which is exactly the same as the modulation rate for this 500 carrier frequency. This was explained with respect to weighted averaging method of response detection (spectrum of the responses was considered) which makes use of F-test. Artifacts were also present in instrument which uses phase coherence to detect responses and the upper limit for artifact free ASSR measurement for head phone is 95 dBHL and for insert ear phone is 105 dBHL (Narne, Nambi & Vanaja, 2006). Picton and John (2004) used different approaches to eliminate artifacts by shifting the aliasing frequency away from the modulation frequency. These approaches include the use of different stimuli such as ‘beats’ which has the energy at carrier frequency ± half of modulation frequency, sinusoidally alternated amplitude modulated tone which has the energy at carrier frequency ± 3/2 times of modulation frequency and carrier frequency ± half of modulation frequency and changing the A/D conversion rates. These approaches have shown to be effective in avoiding artifacts when ASSR is recorded using weighted averaging method. It is not known whether these techniques will help in reducing artifacts in ASSR recorded using phase coherence method. Another approach which can probably shift the aliasing frequency away from the modulation frequency is using a carrier frequency which is not an integer multiple of sampling frequency (Picton & John, 2004). Research needs to be done to check whether changing the carrier frequency can avoid the artifacts or enhance the dynamic range of ASSR for artifact free measurements. So, the current study was aimed to investigate whether changing the carrier frequency can avoid artifacts while recording ASSR using phase coherence method. The study also aimed at determining the upper limit for artifact free ASSR measurements for stimuli presented through a bone vibrator.

Method

Participants

Thirty individuals with profound hearing loss ranging in age from 18 to 40 years participated in the current study. ASSR was recorded from 15 participants for stimuli presented through head phone and from 15 participants for stimuli presented through a bone vibrator. It was ensured that the subjects did not show any behavioral responses to mixed modulated stimuli used for recording ASSR at the presentation level used in the experiment.

Instrumentation

A calibrated two channel diagnostic audiometer Madsen OB 922 audiometer with TDH 39 headphone and Radio ear B71 bone vibrator was used to estimate the behavioral thresholds.

GSI- Audera version (1.0.2.2) was used to record ASSR as well as to obtain behavioral thresholds to mixed modulated stimuli presented through headphone and bone vibrator.

Procedure

Pure tone audiometric thresholds and behavioral thresholds to the modulated tones were measured using modified Hughson & Westlake (Carhart & Jerger, 1959) procedure. Behavioral thresholds to modulated stimuli were obtained at 500, 1000, 2000 and 4000 Hz, hereafter referred to as conventional carrier frequencies, and 522, 1022, 2022, & 4022 Hz, hereafter referred to as experimental carrier frequencies, in the current study. These measurements were carried out to ensure that the participants meet the subject selection criteria.

For recording ASSR, subjects were seated comfortably in a reclining chair and they were asked to relax or sleep. Electrode sites were cleaned using skin prepping gel. Silver chloride electrodes were used to record the ASSR using three electrode placement. For air conduction measurement, inverting electrode was placed on the test ear mastoid, non inverting electrode was placed on the fore head and ground electrode was placed on the mastoid of non test ear. For bone conduction measurements non inverting electrode was placed at vertex and the site for inverting and non inverting electrodes were same as that used for air conduction measurements. It was ensured that electrode impedances were less than 5 k Ohms and inter electrode impedance was less than 2 k Ohms.

For air conduction measurements supra aural headset was placed over the pinna and for bone conduction measurements a bone vibrator was placed on the fore head. ASSRs were recorded for both conventional carrier frequencies, 500, 1000, 2000 and 4000 Hz as well as for experimental carrier frequencies 522, 1022, 2022 and 4022 Hz in all the subjects. ASSR measurements were performed using high modulation frequency of 74 Hz for 500 & 522 Hz , 81 Hz for 1000 & 1022 Hz, 88 Hz for 2000 and 2022 Hz, and 95 Hz for 4000 & 4022 Hz carrier frequencies. Testing was initiated at the maximum limits of instrument and the intensity was varied in 5 dB steps to find out the highest intensity level at which artifact free ASSR measurements can be obtained. Response was determined automatically by the instrument using phase coherence method.

Results

It was observed that less number of individuals had artifacts for experimental carrier frequency when compared to conventional carrier frequencies. Figure 1 and 2 depicts the number individuals with artifacts for conventional and experimental carrier frequencies for air conducted and bone conducted stimuli. From the figures it is clear that as the carrier frequency increases the number of individuals with artifacts reduces for both conventional and experimental carrier frequencies obtained through headphone and a bone vibrator.

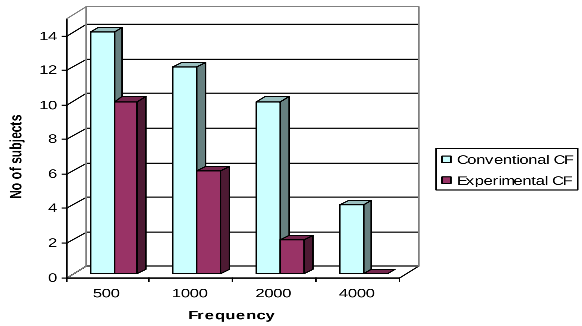

Figure 1: Number of individuals with artifacts for air conducted stimuli

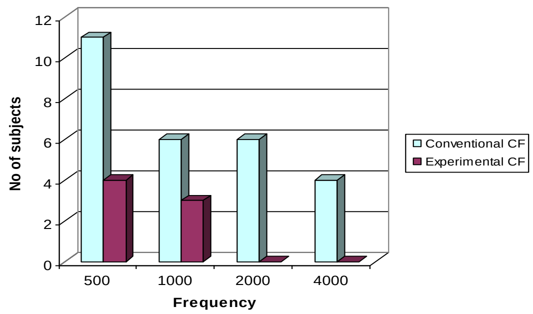

Figure 2: Number of individuals with artifacts for bone conducted stimuli

Overall percentage of subjects in whom artifacts were observed is more for air conduction transducer when compared to bone conduction transducer. Table 1 depicts the percentages of subjects in whom artifacts were observed for conventional and experimental carrier frequencies recorded using air conduction and bone conduction transducer.

Table 1: Percentage of subjects with artifacts for conventional & experimental carrier frequencies

Frequency	**Percentage (%)**	
	Head phone	**Bone vibrator**
500	93.3	91.6
1000	80.0	46.15
2000	66.6	40.0
4000	26.6	26.6
522	66.6	33.3
1022	40.0	23.07
2022	13.5	0.0
4022	0.0	0.0

It was observed that the minimum level at which artifacts occurred was higher for experimental carrier frequencies when compare to conventional carrier frequencies. Table 2 shows the mean and standard deviation of minimum levels at which artifacts occurred across the carrier frequencies for air conducted and bone conducted stimuli and maximum intensity at which artifact free ASSR can be recorded.

Table 2: Mean and SD of minimum level at which artifact occurred and the maximum limit for artifact free ASSR measurement in dBHL

Frequency	Transducer			
	Head phone		Bone vibrator	
	Lowest level at which artifacts occurred Mean (SD)	Max limit for obtaining artifact free ASSR	Lowest level at which artifacts occurred Mean (SD	Max limit for obtaining artifact free ASSR Max limit
500 Hz	98.57 (4.97)	85	56.81 3.37	45
522 Hz	106.0 (3.94)	95	60.0 0.00	55
1000 Hz	109.16 (6.33)	90	73.33 2.58	65
1022 Hz	112.5 (3.94)	100	78.33 5.00	70
2000 Hz	108.0 (5.37)	95	80.83 6.40	65
2022 Hz	110 (0.00)	105	>80	80
4000 Hz	112.5 (5.00)	100	70.00 0.00	65
4022 Hz	>115	115	>70	70

Discussion

In the present study it was found that using the experimental carrier frequency reduces the presence of artifacts. The exact sampling frequency that is used in instrument is not known. However Small and Stapells (2004) reported that commercially available ASSR systems use the A/D to conversion rates of 500 Hz or 1000 Hz as default setting. So it was assumed that this instrument also uses similar A/D rate and the carrier frequencies were changed in such a way that they were not integer multiple of 500 Hz or 1000 Hz. Results revealed that using the experimental carrier frequency reduced the occurrence of artifacts. This supports the notion that these artifacts might be due to electro magnetic aliasing effect. The change in carrier frequency may not allow the electromagnetic carrier signal to alias at the modulation frequency if the A/D rates are 500 Hz or 1000 Hz (Picton & John, 2004). Similar results have been reported by other investigators when they changed the sampling rate (Picton & John 2004; Small & Stapells 2004)

The artifact reduction for stimuli of low frequencies (522 & 1022 Hz) is less when compared to high frequencies (2022 & 4022 Hz). The persistence of artifacts at low frequencies may be attributed to physiological artifacts. The artifacts may be of vestibular origin. Vestibular stimulation is larger at low frequencies when compared to high frequencies (Townsend & Cody, 1971; Todd, Cody & Banks, 2000). Small and Stapells (2004) reported that vestibular evoked myogenic potential from inion muscle could be recorded by an electrode placed on the nape. However in the present study electrodes were placed on mastoids and forehead/vertex. This electrode placement is not suited for picking vestibular evoked myogenic potentials. There are reports of a negative potential N3 generated from the vestibular nuclei through stimulation of saccule (Nong, Ura & Noda, 2000) which could be picked up by using conventional electrode placements (Fore head/Vertex to mastoid) in profound hearing loss individuals. An investigation by Narne, Nambi and Vanaja, (2006) also supported the possibility of vestibular artifacts while recording ASSR at high intensity based on latency calculations from the phase delay which falls around 3-5 msec. They reported that these physiological artifacts mainly contaminated the ASSR elicited by 500 Hz carrier signal. However in the current study the artifacts persisted for 1022 Hz carrier signal also. Occurrence of artifacts at this frequency may also be of vestibular origin. Vestibular stimulation by 1000 Hz acoustic signal has also been reported in the literature (Cheng, Huang & Young, 2003; Welgampola & Colebatch, 2001). Another possible reason for obtaining more artifacts at low frequencies are related to the electrical energy required to drive the oscillator. It has been reported that less electrical energy is required to drive the oscillator at high frequencies (2000 Hz & 4000 Hz) when compared to low frequencies (Small & Stapells, 2004). So the electromagnetic energy that radiated during the generation of high frequency signals will be less when compared to low frequency signals which in turn might reduce the amplitude of electromagnetic stimulus artifacts. A third reason may be that the higher carrier frequencies will be away from the EEG low pass filter setting and thus stimulus artifact would be smaller in amplitude (Small & Stapells, 2004).

Results revealed that there were fewer artifacts for bone conducted stimuli when compared to air conducted stimuli. In the current study the bone vibrator was placed on the forehead and the electrodes were placed on mastoids and vertex. For air conduction testing the electrodes was placed on the mastoids and forehead. So the physical proximity between the transducer and the electrode was more in case of bone vibrator when compared to headphone. This might have reduced the amplitude of electromagnetic energy reaching the electrode which in turn probably reduced the occurrence of artifacts. Also forehead placement of the bone oscillator might result in less vestibular stimulation, possibly due to the different mode of stimulation compared with temporal bone placement (Small & Stapells, 2004). In the current study ASSR for air conducted and bone conducted stimuli was not obtained from the same subject due to time constraints. The individual variability among the subjects may also have accounted for the difference in the percentage of subjects in whom artifacts were observed.

The upper limits for artifact free ASSRs elicited by experimental carrier frequencies were high when compared to ASSRs elicited by conventional carrier frequencies. This may be because experimental carrier frequencies reduced the electromagnetic artifacts and were mainly contaminated by physiological artifacts. The physiological artifacts might occur at little higher intensities when compared to stimulus artifacts and this probably enhanced the upper limits for artifact free ASSR measurements for experimental carrier frequencies.

It can be concluded from the present study that percentage of subjects in whom artifacts were observed for conventional carrier frequencies are higher when compared to experimental carrier frequencies. The important clinical implication of the current study is that the experimental carrier frequencies can be used for threshold estimation as the dynamic range for artifact free ASSR measurement is higher for experimental carrier frequencies when compared to conventional carrier frequencies.

References

Aoyagi, M., Kiren, T., Furuse, H, Fuse, T., Suzuki, Y. & Yokota, M. (1994). Pure-tone threshold prediction by 80 Hz amplitude-modulation following response. *Acta Otolaryngology, Supplement, 511*, 7–14.

Carhart, R. & Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Research*, 24, 330–45.

Cheng, P.W., Huang, T.W. & Young, Y.H. (2003). The influence of clicks versus short tone bursts on the vestibular evoked myogenic potential. *Ear and Hearing, 24,* 195-197.

Cone-Wesson, B., Rickards, F., Poulis, C., Parker, J., Tan, L. & Pollard, J. (2002). The auditory steady-state response: clinical observations and applications in infants and children. *Journal of the American Academy of Audiology*, *13*, 270-282.

Gorga, M.P., Neely, S.T., Hoover, B. M. Dierking, D.M., Beauchiane, K.L. & Manning.C (2004). Determining the upper limits of stimulation for auditory steady state response measurements, *Ear & Hearing*, *25*, 302 – 307.

Luts, H. & Wouters (2005). Comparision of MASTER and AUDERA for measurement of auditory steady state responses. *International Journal of Audiology, 44*, 244-253.

Narne, V. K., Nambi, P. A. & Vanaja, C.S. (2006). Artifactual responses in auditory steady state responses. Paper presented at 38th Annual Conference of the Indian Speech and Hearing Association, Ahmedabad, India.

Nong, D.X., Ura, M. & Noda, Y. (2000). An acoustically-evoked short latency negative response in profound subjects. *Acta Otolaryngologica*, *128,* 960-966.

Picton, T,W. & John,M. (2004). Avoiding electromagnetic artifacts when recording auditory steady state responses. *International journal of audiology, 15,* 541-554

Rance, G, Dowell, R.C., Rickards, F.W., Beer, D.E. & Clark, G.M. (1998). Steady state evoked potential and behavioral hearing thresholds in a group of children with absent click evoked auditory brainstem response. *Ear & Hearing*, *19,* 48-61.

Rance, G., Rickards, F.W., Cohen, L.T., Burton, M.J. & Clark, G.M. (1993). Steady state evoked potentials. *Advancements in Otorhinolaryngology*, *48*, 44-48.

Small, S. A. & Stapells, D. R. (2004). Artifacutal responses when Auditory Steady State Responses, *Ear and Hearing*, *25*, 611-623.

Swanepoel, D., Schmulian, D. & Hugo, R. (2004). Establishing normal hearing with the dichotic multiple frequency auditory steady state response compared to an ABR protocol. *Acta Otolaryngology*, *124*, 62-67.

Todd, N., Cody, P. & Banks, P. (2000). A saccular origin of frequency tuning in myogenic vestibular evoked potentials. *Hearing Research*, *141*, 180-188.

Townsend, G. L. & Cody, D. (1971). The averaged inion response evoked by acoustic stimulation: its relation to the saccule. *Annals of Otology, 80,* 121-132.

Welgampola, M.S. & Colebatch, J.G. (2001). Characteristics of tone burst-evoked myogenic potentials in the sternocleidomastoid muscles. *Otology and Neurotology, 22,* 796-802.