Effect of stimulus polarity on speech evoked auditory brainstem response

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Abstract

The aim of the present study was to investigate the effect of stimulus polarity on speech evoked auditory brainstem response (ABR). In order to accomplish it, speech evoked ABR was recorded with various stimulus polarities from 17 normally hearing adults. The result of the study shows differential effect of stimulus polarity on components of speech evoked ABR. Latency of peaks for onset, sustained and offset responses of speech evoked ABR were found to be not significantly different across stimulus polarities. In contrast, the amplitude of first formant and high frequency components was found to be significantly reduced for alternating polarity compared to single polarity, while amplitude of fundamental frequency response was not affected by polarity of the stimuli. Thus speech evoked ABR may be recorded using single polarity rather than using alternating polarities.

Introduction

Auditory brainstem response (ABR) was discovered by Jewett and his colleagues in early 1970s.[1,2] Since then, ABR has been widely used clinically for detecting neural pathologies[3,4] and to determine hearing threshold in difficult-to-test population.[5] The ABR can be evoked using a variety of stimuli, such as click, tone-burst,[6] speech[7] and electric impulses.[8] Traditionally, the ABR is recorded using click or tone-burst stimuli, with five to seven waves or peaksfor the stimulus onset in the initial 10 ms of stimulus presentation. This response is named as transient portion or response and it is evoked by brief and non-periodic portion of the stimuli. However, when speech stimuli are used for evoking ABR, it elicits transient response for stimulus onset and sustained response for periodic features of speech, named as frequency following response (FFR).[9] The transient portion of the ABR for speech is similar to that observed for clicks, while the sustained portion shows periodic response to fundamental frequency and vowel formants, and it reflects phase-locking to the waveform of the stimulus. The FFR for speech stimulus shows responses that follow the frequency of its envelope and spectral frequency of the stimulus which are referred as envelop FFR and spectral FFR respectively by Aiken and Picton.[10] Stimulus parameters such as stimulus type, intensity, polarity, duration, rise-time, and frequency of the tone-burst are shown to affect latency and amplitude of peaks of the ABR. The stimulus polarity refers to the initial deflection of diaphragm of the transducer with reference to the tympanic membrane when the stimulus is presented. Three stimulus polarities, *i.e.* rarefaction, condensation and alternating, have been used to record the ABR and the stimulus polarity is found to affect latency, amplitude and morphology of the waveforms.[11-13] A rarefaction stimulus produces an initial outward movement of the earphone diaphragm which leads to an outward movement of tympanic membrane. In contrast, condensation polarity stimulus produces an inward movement of the diaphragm resulting in inward movement of tympanic membrane, and for alternating polarity, the stimulus polarity alternates between rarefaction and condensation polarities.

Various investigators have studied the effect of stimulus polarity on the ABR using click and tone-burst stimuli.[11-20] These studies have shown difference in the latency and amplitude of the waves of the ABR obtained with rarefaction and condensation polarity. Fowler[11] assessed the effects of stimulus polarity on click evoked ABR in normal hearing adults, and found that the waves I, III and V of the ABR was shorter in latency for rarefaction click than condensation click. Similarly, Rawool[16] evaluated the effects of stimulus polarity of clicks on the ABR in older adults. She found that the latencies of wave II and V were significantly shorter for rarefaction clicks than for condensation clicks. Similar finding of significantly shorter wave V latency for rarefaction clicks has been reported by various investigators in normally hearing listeners.[17,18] Condensation clicks elicit longer latency because, initially it produce hyperpolarization of the cochlear hair cells followed by depolarization, thus resulting in longer latencies of ABR components, whereas, rarefaction clicks initially produce depolarization and generates response of shorter latency.[21] In contrast, a shorter latency for wave V is also observed for condensation clicks in a small group (15-

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30%) of normally hearing listeners by some other researchers.[17,19,22] Borg and Lofqvist[19] studied the effect of stimulus polarity using 2000 Hz haversine pulse and reported that the latency of wave V was on average 0.1 ms shorter for rarefaction stimuli in normally hearing listeners. Fowler[11] investigated the effect of polarity of tone pip on the ABR among normally hearing listeners. The latency difference for waves between rarefaction and condensation stimuli was found to be inversely related to stimulus frequency *i.e.* higher the frequency of tone pip smaller was the ABR latency difference. Similar results have been reported by Orland and Folsom.[14]

From the above studies it can be observed that stimulus polarity does effect the ABR waves for click and tone bursts, and hence it can be expected that there may be a significant effect of stimulus polarity on speech evoked ABR. In addition, it has been reported that the polarity effects observed for click ABR between rarefaction and condensation polarity stimuli cannot be generalized to tone burst ABR.[23] Further, although the effect of stimulus polarity has been extensively studied for simple stimuli, such as tone burst and click, these observations cannot be generalized to complex sounds such as speech. Hence, there is a need to understand the effects of stimulus polarity on speech evoked ABR, as there is a dearth of information on the influence of stimulus polarity on speech evoked ABR. This aspect has to be considered in view of application of speech evoked ABR, in understanding speech perception in noise, speech perception in reading impairments[24,25] and also to monitor plastic neural changes during auditory training.[26,27] To conclude, it is possible that stimulus polarity may differentially affect various measures of speech evoked ABR, and hence there is a need to investigate the effect of stimulus polarity on speech evoked ABR.

The speech evoked ABR has been recorded by some investigators using single polarity stimuli[10,28,29] as well as alternating polarity.[9] However, these studies did not compare the effect of stimulus polarity on the speech evoked ABR. The goal of present study was to understand the effects of stimulus polarity on speech evoked ABR in normally hearing listeners.[30]

Materials and Methods

Participants

17 individuals (8 males and 9 females) in the age range of 17 to 30 years with a mean age of 20.7 years participated in the study. All the participants had pure-tone thresholds less than 15 dB HL at octave frequencies between 250 Hz to 8000 Hz and speech identification score greater than 90% at 40 dB SL (ref: pure-tone average at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) in both ears. Immittance evaluation done to ensure normal middle ear function revealed *A* type tympanogram with acoustic reflexes present at normal levels. None of the participants had history of neurologic or otologic disorder.

Recording of speech evoked auditory brainstem response

The speech evoked ABR was recorded using synthetic speech sound /da/ of 40 ms duration, used by various earlier investigators.[9,28,30,31] It was obtained from the Auditory Neuroscience Lab of Nina Kraus and colleagues at Northwestern University. The stimulus consisted of stop burst in the beginning, characterized by an inharmonic and broadband frication, followed by a harmonically rich and spectrally dynamic formant transition (refer to the study by Johnson *et al.* 2005 for a detailed description). This stimulus was selected as it is shown to elicit clear and replicable ABRs.[28,30-32] The stimulus was delivered through Etymotic ER-3A insert earphones with a repetition rate of 7.1/second at 80 dB nHL intensity (Figure 1).

During ABR recording, participants were seated on a reclining chair in a comfortable position in a sound-attenuating electrically shielded room. The speech evoked ABR for different polarity stimulus was recorded using IHS Smart EP version 3.92 (Intelligent hearing systems, FL, USA) evoked potential system. Responses were differentially recorded from Ag-AgCl electrodes with non-inverting electrode placed on vertex, inverting electrode on lower forehead and ground placed on the nasion. This electrode montage was used in order to minimize the preferential recording of activity from either side, and hence midline electrode sites were used. The electrode impedance was less than 5 kΩ for all the electrodes and inter-electrode impedance was less than 2 kΩ. The speech evoked ABR was online band-pass filtered from 50 Hz - 1500 Hz and response was amplified 50,000 times. An analysis window of 70 ms with 10 ms pre-stimulus interval was used. Speech evoked ABR was elicited separately using rarefaction, condensation and alternating polarities and the order of the polarities was randomized. Two blocks of 3000 artifact free sweeps were collected for each polarity to check for the replication of waveforms. Individual sweeps exceeding 25 μV were rejected online.

Data analysis

The response waveforms were analyzed and the latencies for onset (wave V and A), offset (peak O), transition (peak C) and fundamental frequency following (peak D, E and F) responses were identified for each participant across the stimulus conditions. These seven peaks of the response (V, A, C, D, E, F, O) to speech stimulus /da/ were manually identified by two experienced audiologists. Data analysis was done as described in the literature.[9,28,32] Wave V was identified as the positive peak near 7 ms immediately before the negative slope, and A was selected as the bottom of the downward slope following wave V. Further, peaks C, D, E, F, and O were identified as the deepest troughs within the expected latency range for each peak, consistent with previous reports in young adults.[9,28,32] Peaks were considered to be absent if they were not replicable between traces. In addition, the sustained portion of the FFR was further analyzed using MATLAB (version 7.10, MathWorks Inc., Natick, MA, USA). The period between 20 and 50 ms after stimulus onset was considered as FFR. Fourier transform analysis was performed and the magnitude of the neural response over the entire period was calculated (RMS amp). Further, the magnitude of spectral components in the frequency regions adjacent the stimulus fundamental frequency (F0 amp: 103-120 Hz), the first formant (F1 amp: 455-720 Hz), and a higher frequency region (HF amp: 721-1154 Hz) were also calculated.

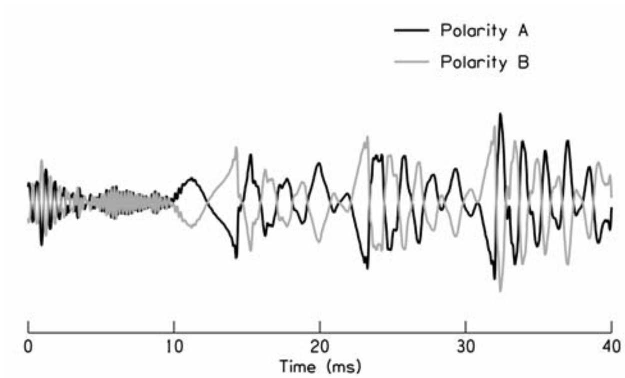

Figure 1. Waveforms showing two polarities of the stimulus /da/, rarefaction (black) and condensation (grey).

Table 1. Mean latency and standard deviation (in parenthesis) of various peaks of speech evoked auditory brainstem response obtained across the stimulus conditions.

Polarity	V	A	C	D	E	F	O
Rarefaction	6.27	7.69	18.89	25.53	35.71	45.74	50.84
	(0.42)	(0.70)	(1.40)	(1.28)	(1.24)	(0.87)	(0.79)
Condensation	6.27	7.30	17.96	25.78	35.97	45.83	51.54
	(0.68)	(0.80)	(0.75)	(1.24)	(1.31)	(1.15)	(1.22)
Alternating	6.16	7.26	18.56	25.25	35.65	45.83	51.88
	(0.55)	(0.73)	(1.29)	(0.85)	(0.81)	(0.87)	(1.41)

Table 2. Mean and standard deviation (in parenthesis) of F0, F1, high frequency amplitude and overall waveform amplitude across the stimulus conditions.

Polarity	F_0 (µV)	F_1 (µV)	HF (µV)	RMS (µV)
Rarefaction	2.92 (0.66)	1.57 (0.18)	1.01 (0.15)	2.13 (0.65)
Condensation	2.84 (0.80)	1.61 (0.23)	1.13 (0.23)	2.62 (1.43)
Alternating	2.97 (0.63)	1.42 (0.14)	0.89 (0.11)	2.67 (1.46)

HF, high frequency; RMS, amplitude and overall waveform amplitude.

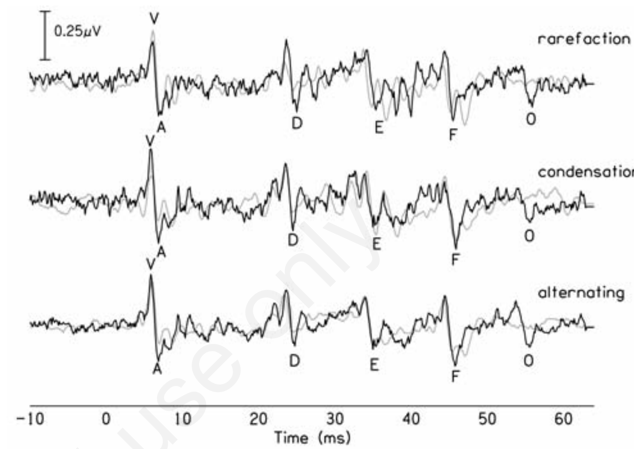

Figure 2. Waveforms showing speech evoked auditory brainstem response responses obtained in two participants for rarefaction (top), condensation (middle) and alternating (bottom) polarities of the stimuli.).

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 15. To investigate the effects of stimulus polarity on latencies of various peaks of speech evoked ABR and amplitude of spectral components, repeated measure ANOVA with stimulus polarity as repeated measure was performed for each peaks and amplitude measures separately. Further, when ANOVA showed a significant effect of stimulus polarity on latencies or amplitudes, a pair-wise comparison (post-hoc analysis) was carried out using Bonferroni test.

Results

In the present study, the speech evoked ABR was recorded from 17 normally hearing young adults using speech sound /da/. Figure 2 shows speech evoked ABR waveforms of two participants recorded using rarefaction, condensation and alternating polarities of the stimulus. The results of the study showed that the onset (wave V and A) and fundamental frequency following response (peak D, E and F) were observed in all the participants (100%) across the stimulus polarities used to record the ABR i.e. rarefaction, condensation and alternating. However, the transition (peak C) and offset (peak O) responses were not observed in all the participants. The transition response was present in 64.7% of the participants for rarefaction and alternating polarities of the stimuli, while for rarefaction polarity it was found to be present in 76.4% of the participants. The offset response was observed in 94.1% of participants for rarefaction polarity and in 82.3% of the participants for condensation and alternating polarities.

Table 1 shows the mean latency of the peaks of speech evoked ABR for three stimulus conditions. From the table it can be observed that the mean latencies were shorter for onset response (wave V and A) and fundamental frequency following response (peak D and E) when alternating polarity stimuli was used. Further, the latency of offset response (peak O) and peak F was shorter for rarefaction polarity, but the latency of transition response (peak C) was found to be shorter for condensation polarity. The data was further subjected to statistical analysis using repeated measure ANOVA, to find out if there is a significant difference between the latency and amplitude of the peaks of speech evoked ABR across the stimulus polarities. Repeated measure ANOVA was carried out separately for each peaks of speech evoked ABR with polarity of the stimulus as repeated measures. Repeated measure ANOVA did not show significant difference for latency of any peaks of speech evoked ABR across the polarities.

Table 2 shows the mean amplitude and standard deviation for various measures of sustained portion of speech evoked ABR. From the table it can be observed that the mean amplitude of F_0 and RMS is higher for alternating polarity stimuli, while mean F_1 and high frequency amplitude is greater for condensation polarity. Repeated measure ANOVA was carried out to identify if the mean amplitudes were significantly different for various measures across the polarities of the stimuli. ANOVA indicated a significant effect of stimulus polarity on F_1 amplitude [$F_{(2, 48)} = 5.214$, $P<0.01$] and HF amplitude [$F_{(2, 48)} = 8.232$, $P<0.005$] and there was no significant difference for mean amplitude of F_0 and RMS. Post-hoc analysis was carried out for F_1 and HF amplitude using Bonferroni test, which demonstrated that the amplitude of F_1 and HF was significantly higher for condensation polarity than alternating polarity. Further no significant difference was found between rarefaction and condensation polarities of the stimuli.

Discussion

In the present study, speech evoked ABR was recorded using synthetic syllable /da/, the results showed that the onset response (wave V and A) and fundamental frequency following response (peak D, E and F) were present in all the participants. But, the offset response (peak O) and transition response (peak C) were present in 64.7% and 82.3% respectively for all the polarities. Johnson *et al.*[9] reported the detection of various peaks of speech ABR in 88 individuals. They reported that the onset and offset responses and peak F were present in 100% of the individuals, while, peak D and E were present in 95 and 98% of the individuals respectively. But, in contrast the present study showed reduced detection of transition response (peak C) and offset response (peak O). This finding in the present study may be attributed to difference in the electrode placement between the studies.

Studies investigating the effect of stimulus polarity on click ABR, has found significantly shorter latency for wave V or some components of ABR for rarefaction clicks, compared to condensation clicks.[11,16-18] This is because a rarefaction click initially depolarizes hair cells within the cochlea and produces response of shorter latency. Whereas, condensation clicks initially produce hyperpolarization of the cochlear hair cells followed by depolarization, resulting in slightly longer latencies of ABR components.[21] However, in the present study, the latency of the transient portion of speech evoked ABR (wave V and A) did not show significant difference across stimulus polarities. This finding in the present study is similar to the observations made by other investigators[33-35] on click evoked ABR, who reported no significant difference for latency of wave V of click evoked ABR. This is explained by the fact that responses to broad-spectrum clicks are dominated by the high-frequency regions of the cochlea (2000 to 4000 Hz) and, therefore, 180° phase shifts would be too small to detect. Further, the stop burst in the present study which evoked the transient portion of speech ABR carried energy between frequencies of 2580-4500 Hz, which also stimulates the high frequency region of cochlea resulting in no significant difference for latency of waves across the polarities.

The results of current study also showed the amplitude of F_1 and HF components obtained for alternating polarity stimuli was significantly smaller than condensation polarity, but the F_0 amplitude was not significantly different. This finding is in agreement with Aiken and Picton[10] and Kraus *et al.*[32] They reported that adding the response obtained for two polarities emphasize the lower-frequency components of the response and reduces the spectral response. Whereas, subtracting the response enhances the higher frequency components, by maximizing the spectral response, and attenuates the envelop response. Thus, reduced HF amplitude for alternating stimulus polarity may be attributed to cancellation of spectral FFR as a consequence of adding the response for two polarities. Further, the results of the study showed no significant difference for amplitude of F_0, F_1 and HF between rarefaction and condensation polarities of the stimuli. This finding in the present study was expected, because reversing the polarity of the stimulus does not alter the spectral characteristics of the stimulus, and hence the response obtained was similar for two polarities of the stimuli. From the present study it can be noted that any polarity of the stimulus (*i.e.* rarefaction, condensation or alternating) can be used to record speech evoked ABR. From literature it is well known that, recording the speech evoked ABR using alternating polarity or adding the response obtained for two polarities aids to minimize cochlear microphonic and the residual stimulus artifact from the response. Based on the results of the present study it is evident that use of alternating stimulus polarity to record speech evoked ABR significantly reduces the amplitude of HF spectral components, compared to single polarity stimuli. Thus, it may be suggested to record speech evoked ABR separately for both polarities separately and either added or subtracted to enhance different parts of the response waveform, or even analyzed as individual polarities. In addition, results of current study also highlights that norms obtained using single polarity stimuli cannot be applied for speech evoked ABR obtained using alternating stimulus polarity.

Conclusions

The present study shows that stimulus polarity does not affect the latency of various peaks of speech evoked ABR. In contrast, the amplitude of various measures was differentially affected, where amplitude of F1 and high frequency spectral components were significantly reduced for alternating polarity, compared to single polarity. But, F0 amplitude was found to be not affected by stimulus polarity used to record speech evoked ABR. Thus, speech evoked ABR may be preferably recorded using single polarity rather than using alternating polarity.

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