Effect of stimuli, transducers and gender on acoustic change complex

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Abstract

The objective of this study was to investigate the effect of stimuli, transducers and gender on the latency and amplitude of acoustic change complex (ACC). ACC is a multiple overlapping P1-N1-P2 complex reflecting acoustic changes across the entire stimulus. Fifteen males and 15 females, in the age range of 18 to 25 (mean=21.67) years, having normal hearing participated in the study. The ACC was recorded using the vertical montage. The naturally produced stimuli /sa/ and /si/ were presented through the insert earphone/loud speaker to record the ACC. The ACC obtained from different stimuli presented through different transducers from male/female participants were analyzed using mixed analysis of variance. Dependent t-test and independent t-test were performed when indicated. There was a significant difference in latency of 2N1 at the transition, with latency for /sa/ being earlier; but not at the onset portions of ACC. There was no significant difference in amplitude of ACC between the stimuli. Among the transducers, there was no significant difference in latency and amplitude of ACC, for both /sa/ and /si/ stimuli. Female participants showed earlier latency for 2N1 and larger amplitude of N1 and 2P2 than male participants, which was significant. ACC provides important insight in detecting the subtle spectral changes in each stimulus. Among the transducers, no difference in ACC was noted as the spectra of stimuli delivered were within the frequency response of the transducers. The earlier 2N1 latency and larger N1 and 2P2 amplitudes noticed in female participants could be due to smaller head circumference. The findings of this study will be useful in determining the capacity of the auditory pathway in detecting subtle spectral changes in the stimulus at the level of the auditory cortex.

Introduction

Speech evoked cortical auditory potentials are frequently used to study the cortical representation of speech sounds in the cortex. The underlying assumption is that speech perception is dependent on neural detection of time varying spectral and temporal cues contained in the speech signal. Central auditory evoked potentials (CAEPs) are an electrical manifestation of the brain response to an auditory stimulus. Although CAEPs are evoked by brief stimuli such as clicks[1] or tone burst,[2] CAEPs can also be elicited in response to natural speech stimuli[3] that are longer in duration and contain time-varying acoustic cues.[4] Though, synthetic speech stimuli elicit a well-defined complex response[5] and also allow the researchers to control certain aspects of the stimulus, it is a far representative of everyday natural speech.[6]

In addition to the CAEPs reflecting the neural detection in response to time-varying cues mentioned earlier, it also reveals changes in amplitude,[7] periodicity,[7] changes in temporal cues (voice onset time of 60 ms),[8,9] changes from a harmonic tonal complex to a noise band with the same spectral envelope[5] and formant frequency changes alone in the ongoing vowels with no amplitude increment[10] which suggests that the CAEPs reflect cortical detection of complex changes in ongoing acoustic cues. These collections of overlapping CAEPs within a single response to ongoing changes in the stimulus are defined as acoustic change complex (ACC).[10] All these studies reported in the literature have used synthetic speech. A study by Ostroff *et al.*[11] investigated cortical potentials in response to naturally produced speech syllable /sei/. The cortical potentials reflected the contribution of the acoustic events contained in the constituent phonemes /s/ and /ei/. The finding suggests that the cortical region activated for the transition from /s/ to /ei/ overlaps with the response of the constituent phonemes. According to them, the possible reason for such an overlap was the failure of cortical neurons to respond to vowel onset when already being activated by the sibilant portion. Further, the cortical activation by the sibilant portion of the stimulus might have blocked the transmission of information about the vowel onset. The other possible reasons for such an overlap of response for an ongoing stimulus include transition in the spectral envelope, amplitude and periodicity. Since the literature on the effect of natural speech on cortical responses is sparse,

there is a need to find out if the transition of second formant frequency in the naturally produced stimuli has any effect on the auditory cortical response.

The other factors, which might affect the cortical responses, include gender differences. The literature has documented the effect of gender on brain activity related to general and emotional intelligence.[12] The female participants consistently demonstrated a higher cerebral metabolic activity.[13] These studies were not directly relevant to evoked related potentials. There is a need to know if gender differences play a role in events related to cortical auditory evoked potentials.

Additionally, the potentials elicited also depend on the transducers used for recording. The transducers are selected based on the purpose of the test, the population being tested, and the intention of the clinician or researcher.[14] There are many types of transducers available for assessing the hearing status of individuals. One among such types of transducers is the earphone, which has low distortion and a relatively flat frequency response with limited output above 8 kHz. However, the possible problems associated with earphones were sound leakage, ear canal collapse, and occlusion and reduced inter-aural attenuation.[14] In addition to the above, this cannot be used for assessing the aided performance.

Another category of transducers is the insert earphone. Insert earphones are used to overcome certain limitations posed by an earphone. The limitations were placement and maintenance of insert earphone in the ear canal during testing. These present a challenge in assessing the hearing status accurately.[15] The insertion depth may affect the resonance frequency of the ear canal.[16,17] It is also difficult to obtain a good airtight seal in individuals having larger ear canals.[15] Due to these limitations, the emphasis has now shifted to the loud speaker as a transducer for presenting the stimuli.

There are some advantages of using a loud speaker as the transducer. It provides a means of assessing the hearing sensitivity for difficult-to-test population such as infants and very young children, who are reluctant to wear, insert earphones.[18] This can also be used to measure the performance in individuals using a hearing aid, which in turn helps to determine the functional gain.[19] Sharma *et al.*[20] assessed the development of central auditory pathway in children wearing hearing aid by acquiring the aided CAEPs when the synthetic stimulus, /ba/, was presented through the loud speaker. The presence of CAEPs provided an objective measure in detecting the sound in aided condition.[21] Purdy *et al.*[22] suggested that CAEPs should be utilized as an objective technique to assess the benefit received from amplification. However, there are practical limitations noticed in relation to the participant and the test room. The participant characteristics reported were slight movement during testing, distance and angle in relation to the loud speaker.[18] Room characteristics involve absorptivity of room, placement of the speaker and suitable seating arrangement.[18] Hence, a knowledge of the limitations posed from each transducer and using appropriate strategies for overcoming the limitations would increase the validity and reliability in assessing the status of hearing. As the transducers have specific applications, it would be useful to know if the type of transducers has any effect on the cortical auditory evoked potentials.

Further, artifacts are a major issue in delineating the desired waveforms with any of these transducers. There are two types of artifacts, *viz*, stimulus and electrical artifacts. The stimulus artifacts can be eliminated with the knowledge of acoustical aspects of stimulus and the protocol used for recording the auditory evoked potentials. The electrical artifacts are eliminated by transducers used for presenting the stimuli and proper grounding. The plastic tube of the insert earphone removes the electromagnetic radiations in the vicinity of the electrode and acoustic time delay allows the electromagnetic radiation to die away before the acoustic signal reaches the eardrum.[23] Even the loud speakers, eliminate electrical artifacts as there is no contact between electrodes and the transducer.

The current study is thus aimed at investigating the effect of stimuli, transducers and gender on cortical potentials in individuals with normal hearing. The specific objectives formulated were to investigate i) the effect of stimuli on the latency and amplitude of ACC ii) the effect of transducers on the latency and amplitude of ACC and iii) the effect of gender on the latency and amplitude of ACC. This was evaluated by using two naturally produced speech stimuli, /sa/ and /si/, presented through the insert earphone and loudspeaker.

Materials and Methods

Participants

Thirty adults (15 males, 15 females) with normal hearing in the age range of 18 to 25 years (mean=21.67 years, SD=2.11 years) participated in the study. All the participants had normal hearing sensitivity in the test ear as revealed by pure tone air-conduction and bone conduction thresholds (<15 dB HL) and speech identification scores (≥80 % at 40 dB SL re: speech reception treshold).[24] Their tympanometric and acoustic reflex findings indicated that the middle ear had normal status. The participants did not have any history of neurological, cognitive or speech and language problems.

Stimulus recording and preparation

Three male speakers whose mother tongue was Kannada (a Dravidian language widely spoken in Karnataka, South India) were chosen to utter the consonant vowel (CV) tokens /sa/ and /si/ with normal vocal effort. These tokens were selected, as the stimuli differ mainly in second formant transition and also because the high frequency and low intensity characteristics of their initial phoneme are difficult to perceive by listeners with hearing loss.[25] Thus, naturally produced /sa/ and /si/ tokens were used as test stimuli. These have unvoiced alveolar fricative consonant combined with either vowel /a/ (low back vowel) or /i/ (high front vowel). A total of six CV (*i.e.*, /sa/ stimuli uttered by three speakers edited to have the same duration. Similarly, /si/ stimuli were prepared) tokens were recorded from three adults using the Adobe Audition (version-3) (Adobe Systems Inc., San José, CA, USA) software in the computer. A 32-bit processor with a sampling rate of 48,000 Hz was used while recording via a microphone (AUD-101XLR, Ahuja Radios, New Delhi, India) placed at a distance of 10 cm from the lips of the speaker.[26] The recorded tokens were group normalized to an average level.

Ten listeners with normal hearing were rated for the naturalness of the recorded CV syllables. Two stimuli, /sa/ and /si/, produced by the same speaker and rated as being natural were selected as the test stimuli. The duration of /sa/ and /si/ was 298.9 and 301 ms respectively. It was seen to it that the consonant duration of /sa/ and /si/ was constant *i.e.*, 149.8 ms. The vowel duration of /sa/ and /si/ was 149.1 and 151.2 ms. respectively. This was done so that the changes in transition portion of ACC could be studied, with respect to changes only in the second formant frequency of the stimuli. The acoustic waveforms and spectrograms of the stimuli were analyzed using Praat software (version -5.1.29, developed by University of Amsterdam, the Netherlands) and are as shown in Figure 1. The stimuli were presented through insert earphone and loudspeaker separately at 65 dB SPL to record ACC. The stimulus level through the insert earphone was calibrated using a 2 cc coupler. The loud speaker at the ear level through the loud speaker was calibrated using a Larson Davis sound level meter (SLM) with free-field microphone.

Procedure for acquiring the acoustic change complex

All the tests were carried out in an air-conditioned sound treated

setup. After ensuring that the participants met the inclusion criteria, the ACC was recorded. A new session was created for each participant in the neuro-scan AEP system by entering and saving the details of the participant in the patient's demographics. The participant was seated comfortably in an armed reclining chair. The electrode sites were cleaned with skin preparing gel. Disc type silver coated electrodes were placed at the test sites using conduction gel. During the recording of ACC, the non-inverting electrode (+) was placed on the vertex (Cz, Fpz, C3 and C4), the ground electrode was on the mastoid of non test ear and the inverting electrode was placed on the mastoid of test ear (Ai). The test ear was either right or left ear. It was ensured that the electrode impedance was less than 5 k Ohms for all the electrodes and the inter-electrode impedance was less than 2 k Ohms.

For recording the ACC, the stimulus /sa/ or /si/ was presented at 65 dB SPL to the test ear through the insert earphone (ER 3A, with frequency ranging from 50 Hz to 8 kHz). Masking the non-test ear was not contemplated considering the level of test signal and the amount of interaural attenuation when an insert earphone is used. The participant was instructed to ignore the signals and watch a movie that was muted and played through a battery-operated laptop. This instruction was made to minimize the movement of the eyeball and blink. He/she was also asked to minimize the head movement. A 5-min break between recording conditions was given. The personal computer based evoked potential system, Neuroscan 4.4 (Stim 2-version 4.4, Compumedics, Charlotte, NC, USA), controlled the timing of stimulus presentation and delivered an external trigger to the evoked potential recording system, Neuroscan 4.4 (Scan 2-version 4.4, Compumedics). To allow for a sufficient refractory period within the stimulus sweep while minimizing the total recording time, an inter-stimulus interval of 700 ms was used.

The evoked responses were analog band-pass filtered online from 0.15 to 100 Hz with 12 dB/octave roll-off. Analysis was carried out in off-line mode. The electroencephalogram channels were converted using an analog-to-digital sampling rate of 1000 times per second. The epoched waveforms were corrected for baseline. Each epoched file in the Fpz channel was visually inspected for higher amplitude. Then those epochs were rejected in all the four channels. The post-hoc filter was set to zero-phase shift and filtered from 1.0 Hz (high-pass filter, 12 dB/octave) to 30 Hz (low-pass filter, 12 dB/octave). Epochs with artifact

measuring in excess of +/- 70 microvolts were rejected. After artifact rejection, a minimum of at least 250 sweeps was included for averaging. Suppose the sweeps were less than 250, the response was rejected and a new recording was started. The epoched file from each channel is as shown in Figure 2.

This procedure was repeated to record the ACC for /sa/ or /si/ stimulus presented through the loud speaker (dB technology, with frequency ranging from 50 Hz to 20 kHz) to the test ear, *i.e.*, either right or left ear of the participant. The loud speaker was located 1 meter away from the participant with 45 degrees Azimuth from the participant and positioned at the level of the test ear, ~1.2 meter from the floor. The participation of the non-test ear was ruled out by presenting a broadband noise through insert earphone at 65 dB SPL, from a calibrated audiometer. The order of testing with the stimuli and transducers was counter balanced on each participant. The ACC was recorded for each stimulus being presented by each of the transducers. The waveform was recorded twice to check for reliability.

Measurement of latency and amplitude of acoustic change complex components

Figure 3. The grand mean waveforms obtained to the /sa/ stimulus presented from insert earphone at electrode sites (Cz, Fpz, C3, and C4). The discrete latency and amplitude of ACC components were analyzed only from the recordings of Cz channel. As reported in a study by Tremblay *et al.*, it was found that morphology and amplitude of N1-P2 were better with Cz recording, *i.e.*, when obtained at mid-central scalp location.[6] The latency of the peak was typically measured at the center. If the waveform contained double peak of unequal amplitudes, the latency was measured at the midpoint between the two. When the peaks were not equal in amplitude, the latency was measured at the center of the larger peak. The N1 and the P2 correspond to the onset response, which are the first positive and negative peaks. This reflects the change in acoustic energy from silent portion to the onset of consonant. The 2N1 and 2P2 correspond to the transition response, which are the second positive and negative peaks respectively. This reflects the transitional change in acoustic energy from consonant portion to the onset portion of the vowel. Figure 4 shows the ACC response for speech /si/ stimulus.
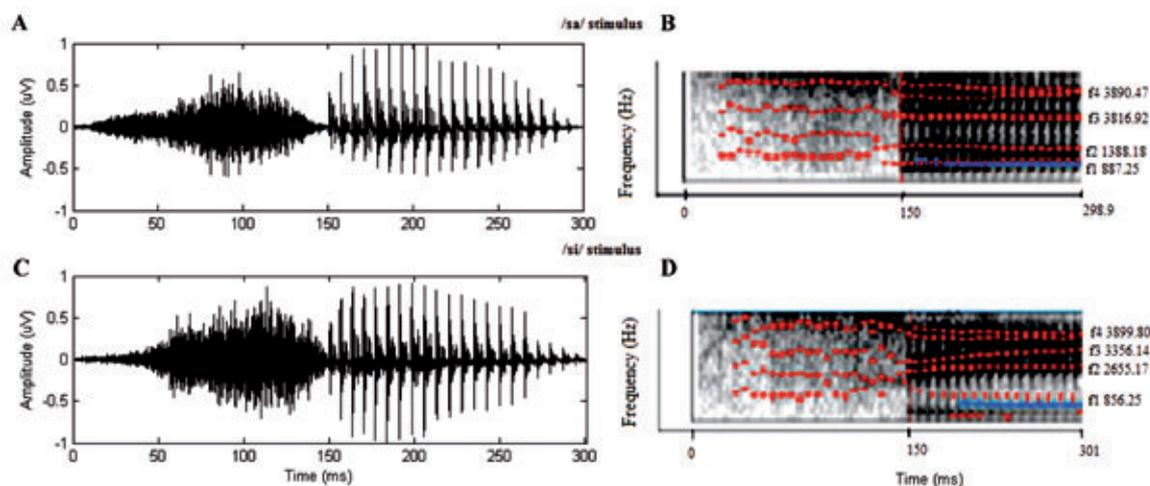
Figure 1. (A) and (C) are the waveforms of /sa/ and /si/ stimuli. For stimuli /sa/ and /si/, the vowel duration is 149.1 and 151.2 ms; and consonant duration is 149.8 ms for each stimulus. For /sa/, the rise time is relatively rapid and the rate of change of formant transition is faster than that for /si/. (B) and (D) are the spectrograms of /sa/ and /si/ stimuli with the fundamental frequency of 133 Hz and 134.6 Hz respectively. The first four formants of each stimulus are depicted in the spectrogram.

Description of the statistical tests

The data obtained were analyzed using Statistical Package for the Social Sciences (SPSS for Windows, version 18) software. The data consisted of three independent variables, in which, stimuli and transducers were within subject parameters; and gender was between subject parameter. In order to note if there was any significant difference in the means of the parameters measured, separate two-way mixed analysis of variance (ANOVA) was carried out for latency and amplitude of ACC. A dependent t-test was used if a significant difference was noticed in stimuli or transducers (within subject parameters) on two-way mixed ANOVA. In addition, an independent t-test was performed if a significant difference was noticed in gender (between subject parameter) on two-way mixed ANOVA.

Results

The latency and amplitude of ACC were obtained for the two stimuli (/sa/ and /si/), presented through the two transducers (insert earphone and loud speaker), in male and female participants. The mean and standard deviation of latency and amplitude of ACC for different stimuli (/sa/ and /si/) presented through different transducers (insert earphone and loud speaker) obtained from male and female participants are given in Tables 1 and 2.

Effect of stimuli and transducers on latency of acoustic change complex

The grand average of ACC waveforms obtained for /sa/ and /si/ stimulus when presented through insert earphone and loudspeaker are depicted in Figures 5 and 6. From Table 1, it was found that the mean

latencies of onset of consonant (N1-P2) and transition from frication to onset of vowel (2N1-2P2) were shorter for /sa/ than /si/ stimulus, presented through either transducer. Further, the mean latencies of N1-P2 and 2N1- 2P2 were shorter for insert earphone than loudspeaker for both the stimuli. A two-way mixed ANOVA was performed to determine the effect of stimuli and transducers on the latency of different components of ACC. The interaction and main effects of mixed ANOVAs conducted on latency of each component of ACC was reported in Table 3. The result revealed no significant interaction effects in any of the components of ACC. However, it was found that there was a significant

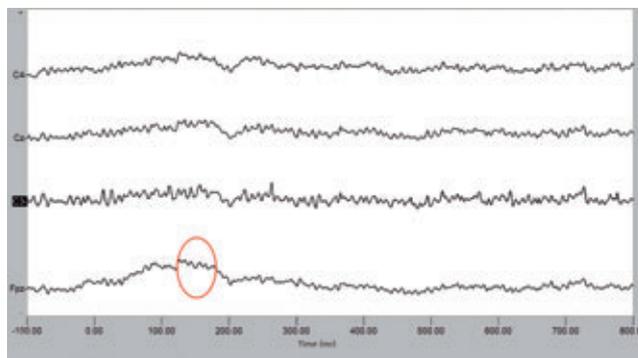**Figure 2. The epoched file for /sa/ stimulus presented through insert earphone. The higher amplitude of epoch in Fpz channel was marked in red circle. Those epochs with higher amplitude were rejected in all the four channels.**
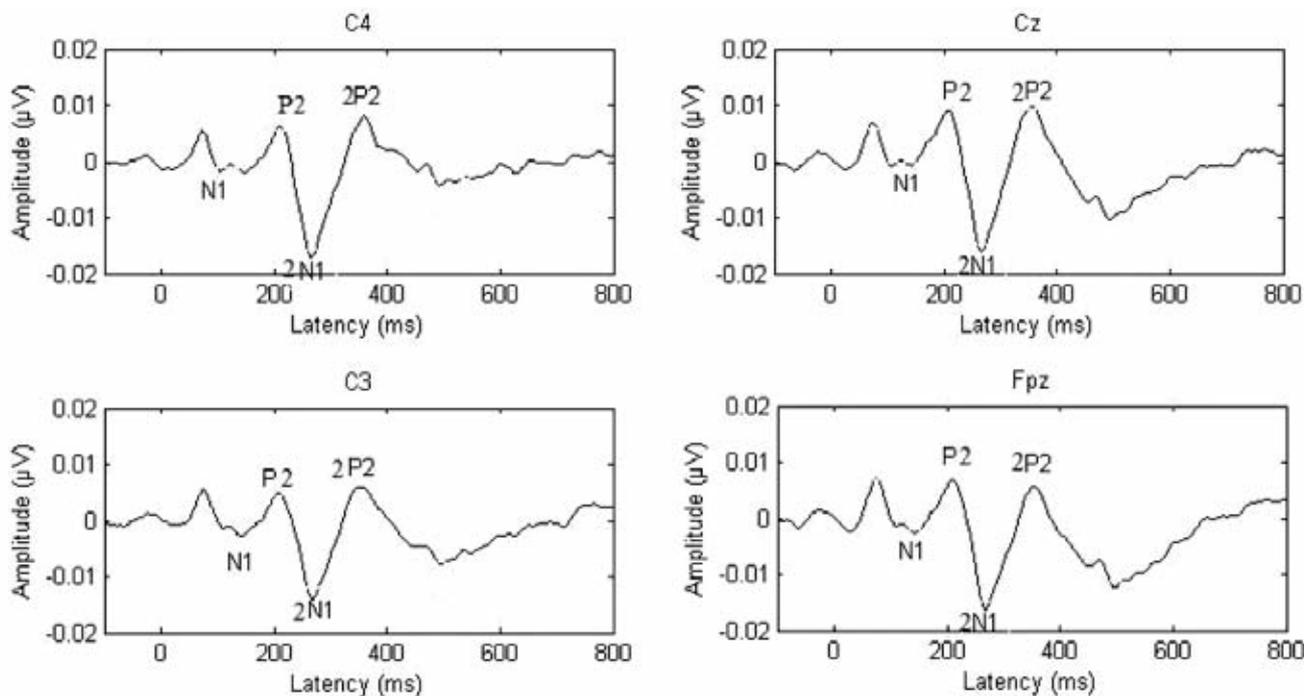

Figure 3. Grand average of acoustic change complex obtained from four electrode channels, in response to /sa/ stimulus. Higher amplitude of N1-P2 amplitudes was noticed from Cz site.

main effect of the stimuli on the latency of 2N1 [F (1, 26)=36.08, P<0.00] and not in other components of ACC. Further, on dependent t-test revealed that the latency of 2N1 was significantly shorter for /sa/ compared to /si/ for insert earphone for both male [t (14)=4.92, P<0.00] and female participants [t (14)=3.46, P<0.00]. A similar trend was noticed for loudspeaker in both male [t (14)=3.92, P<0.00] and female [t (14)=4.17, P<0.00] participants.

From Table 2, it was found that the mean amplitudes of N1-P2 and 2N1-2P2 were larger for /sa/ than /si/ stimulus for either transducer. The mean amplitude of 2N1-2P2 was larger for loudspeaker than insert earphone for both the stimuli. However, the mean amplitude of N1 was larger for /sa/ stimulus presented through insert earphone than through loudspeaker, in the male group. Further, two-way mixed ANOVA was carried out to find out the effect of stimuli and transducer on the amplitudes of the different components of ACC. The interaction and main effects of mixed ANOVA conducted on amplitude of each component of ACC is depicted in Table 4. This revealed that there was no significant interaction effect and main effect on the amplitude of any of the components of the ACC.

Effect of gender on latency and amplitude of acoustic change complex

The mean latencies of N1-P2 and 2N1-2P2 were shorter in female participants than male counterpart. Two-way mixed ANOVA revealed that there was a significant main effect in latency of 2N1 [F (1, 26)=10.56, P<0.00] alone between male and female participants. In order to know the effect of stimuli and transducer on latency of 2N1 in male and female participants, independent t-test was performed. The result revealed that, when /sa/ stimulus was presented through the insert earphone, a significant difference was noticed in latency of 2N1 [t (28)=0.94, P<0.00], with the latency being earlier for female than male participants. Whereas, when the /sa/ stimulus was presented through the loud speaker, there was no significant difference between the male and female participants. Further, for /si/ stimulus, there were no differences in the latencies, in any of the transducers, between male and female participants.

In case of amplitude, female participants had larger amplitude than male counterparts in all the components of ACC. Two-way mixed ANOVA revealed that there was a significant main effect in amplitudes of N1 [F (1, 26)=6.97, P<0.01] and 2P2 [F (1, 26)=10.27, P<0.00] between male and female participants. In order to know the effect of stimuli and transducer on amplitudes of N1 and 2P2 component of ACC in male and female participants, independent t-test was performed. The amplitude of N1 was not significantly different for each stimulus, presented through two transducers. However, in the amplitude of 2P2, significant difference was noticed [t (28)=3.68, P<0.00] between male and female participants, with larger amplitude being noted in female than male participants for /sa/ stimulus presented through insert earphone. Similar results were observed for /si/ stimulus presented through the insert earphone [t (28)=2.30, P<0.01]. When /sa/ was presented through the loud speaker, there was no significant difference in the amplitude of 2P2 between male and female participants. However, when /si/ was presented through the loud speaker, the amplitude was larger in female compared to that in male participants, and this difference was found to be statistically significant [t (28)=1.93, P<0.03].

Discussion

The purpose of this study was to explore the effect of stimuli, transducer type and gender on components of ACC.
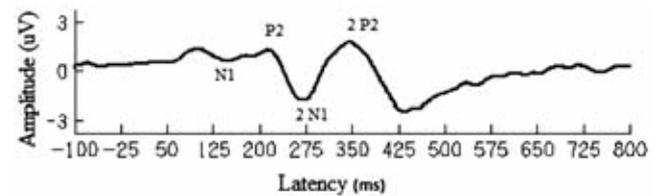

Figure 4. Acoustic change complex elicited by speech stimulus /si/. The N1 and P2 correspond to onset of consonant; the 2N1 and 2P2 correspond to onset of vowel.
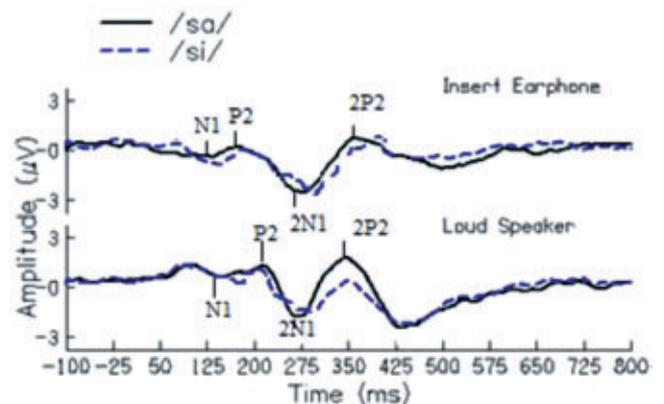
Figure 5. The latency and amplitude of acoustic change complex (ACC) for /sa/ and /si/ stimulus presented through insert earphone and loudspeaker. The latency of onset and transition of response were earlier for /sa/ than for /si/ stimulus, for each transducer. Mean amplitude of onset and transition portions of ACC was larger for /sa/ than /si/ stimulus in either transducer.
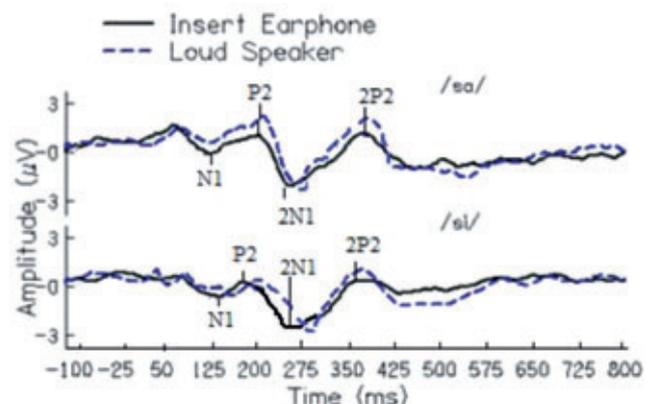
Figure 6. The latency and amplitude of acoustic change complex (ACC) for /sa/ and /si/ presented through insert earphone and loudspeaker. The latency of onset and transition of ACC were earlier for insert earphone than loudspeaker for each stimulus. Amplitude of transition portion of ACC was larger for loudspeaker than insert earphone for each stimulus. In onset portion of ACC, the N1 mean amplitude was larger for /sa/ stimulus presented through insert earphone than loudspeaker.

Effect of stimuli on latency and amplitude of acoustic change complex

Effect of stimuli (/sa/ and /si/) on latency

The onset response in late latency response is normally elicited at 100 ms (N1).[27,28] The N1 component of ACC corresponds to N1 of usual late latency response.[4] In the present study, the mean latencies of N1-P2 are found to be earlier for /sa/ than /si/ stimulus presented through either transducer. This could be because of higher energy in the initial portion of /sa/ than /si/ which can be visualized in the waveforms of the two stimuli (Figure 1). In addition, the latencies of onset components of CAEP are sensitive to faster rise time, resulting in decreased latencies.[29]

From Figure 1 it is clear that the rate of formant transition is different for /sa/ and /si/ stimulus. In /sa/ stimulus the formant transition is much more rapid than /si/ stimulus. Thus, the latency of 2N1 was found significant, with earlier latency being noted for /sa/ than /si/ stimulus presented through insert earphone and loudspeaker. Further, the latency of 2P2 was earlier for /sa/ than /si/ stimulus presented through either transducers, but did not account for significant difference. The finding was supported by Ruhm[30] who reported decrease in latency of CAEPs as a function of rapid rate of change in the signal frequency. Further, it has been documented that different frequencies of different speech sounds activate different regions of the auditory cortex. The low frequency sounds generally activate the lateral and anterior areas of the superior surface of the temporal lobe.[31] However, the high frequency speech sounds are generally represented on the medial portion of the superior surface of the temporal lobe.[32] Since the low frequency transition portion of vowel /a/ in /sa/ stimulus may be elicited from lateral portion of cortex, the time taken to process the stimulus is less than the

high frequency transition portion of vowel /i/ in /si/ in both the transducers. Further, in the studies reported in the literature, it was demonstrated that the ACC reflects small changes of the second formant frequency (Ostroff JM, unpublished doctoral dissertation, 1999). In the present study too, it is demonstrated that when the duration of the consonant and the first formant were similar, it is possible to study the influence of the second formant frequency on the transition component of ACC. Additionally, the energy of vowel in both stimuli were similar. This was verified by acoustic measurement and it was observed that the vowel /a/ portion of /sa/ was similar to the vowel /i/ portion of /si/ stimulus. Thus, the latency difference observed was due to the formant frequency variation alone between the two stimuli.

Effect of stimuli on amplitude

Since both the stimuli are presented at the same calibrated intensity level in either transducer, the results reveal no significant difference in any of the amplitudes of ACC. As the initial portion of frication of /sa/ has higher energy and faster rise time, the mean amplitude of N1-P2 were found larger for /sa/ than /si/ stimulus. The energy at the transition portion of both the stimuli was similar, which was analyzed through acoustical measure. However, the mean amplitudes of 2N1 and 2P2 were larger due to rapid change of formant transition in /sa/ than /si/ stimulus.

Effect of transducers on latency and amplitude of acoustic change complex

Effects of transducer on latency

A comparison of each component of ACC between the transducers using the two different stimuli can be discussed in terms of the accu-

Table 1. Mean and standard deviation of latency (ms) of different components of acoustic change complex for different transducers and stimuli (/sa/ and /si/) presented to the male and female participants.

Transducers	Latencies (ms)	/sa/ Male M±SD	/sa/ Female M±SD	/si/ Male M±SD	/si/ Female M±SD
Loud speaker	N1	125.20±15.10	124.90±10.40	139.75±9.60	131.70±10.60
	P2	215.00±3.80	212.90±9.70	216.15±11.30	216.15±11.05
	2N1	281.50±10.80	269.30±12.10	290.75±11.40	276.85±9.65
	2P2	367.50±13.80	356.00±18.40	367.00±13.45	358.45±17.35
Insert earphone	N1	120.45±9.85	214.60±12.35	132.35±15.95	131.60±8.85
	P2	213.70±14.80	212.35±11.60	214.55±16.35	213.65±14.95
	2N1	276.20±9.60	264.85±12.55	285.10±10.50	270.90±9.90
	2P2	364.50±16.40	353.65±18.20	370.50±14.85	353.65±18.20

M, mean; SD, standard deviation.

Table 2. Mean and standard deviation of amplitude (µV) for different transducers and stimuli (/sa/ and /si/) obtained from male and female participants.

Transducers	Amplitudes (µV)	/sa/ Male M±SD	/sa/ Female M±SD	/si/ Male M±SD	/si/ Female M±SD
Loud speaker	N1	-1.40±0.95	-1.55±0.40	-0.60±0.62	-0.65±0.65
	P2	1.15±0.55	1.70±0.80	0.89±0.60	1.55±1.30
	2N1	-3.60±1.20	-4.05±1.75	-3.55±1.70	-3.95±1.80
	2P2	1.75±1.10	1.95±1.10	1.30±0.70	2.55±1.25
Insert earphone	N1	-1.61±0.90	-1.10±0.90	-0.56±0.90	-0.65±0.55
	P2	0.70±0.20	1.30±0.70	0.55±0.50	1.05±1.20
	2N1	-3.55±1.45	-3.55±1.35	-3.45±2.65	-3.40±1.05
	2P2	1.00±0.85	1.55±1.45	1.15±0.95	1.70±1.25

M, mean; SD, standard deviation.

racy of the calibration of the different stimuli presentation and frequency response of transducers can be argued. At the position of the test ear of the participants, both the stimuli read 65 dB SPL on the SLM in each transducer. For both the stimuli, a comparison between the transducers revealed no significant difference in latencies. This is because the spectra of naturally produced speech stimuli /sa/ and/ si/ are delivered within the frequency responses of the insert earphone (50 Hz-8 kHz) and loudspeaker (50 Hz-20 kHz). Although there was a longer arrival time of 2.8 ms. for the loud speaker compared to insert earphone, there was no statistical difference in the latencies of ACC.

Effect of transducers on amplitude

There was no significant effect of the transducers on amplitude of ACC. This was true for both the stimuli. This is because, each transducer is calibrated and the stimulus is presented at the same intensity through the transducers. The mean amplitudes of 2N1 and 2P2 component of ACC were found larger for both the stimuli when presented through the loud speaker than insert earphone. This could be because the resonance frequency of the ear canal is not affected while recording the ACC through the loud speaker. However, the depth of insert earphone might have obscured the resonance property of the ear canal. The reason for the larger amplitude of N1 component for /sa/ stimulus presented through insert earphone in male participants is not clear.

Effect of gender on latency and amplitude of acoustic change complex

Gender differences in human brain organization are well documented based on anatomical asymmetry and physiological process. Many of the anatomical differences between genders cluster in the temporoparietal regions of the brain, which sub-serve the asymmetric representation. Knight et al.[33] reported that N1 originates from superior temporal gyrus. P2 is generated from the sylvian fissure.[34] It was found that the latency occurred earlier in female participants than in male counterparts in all the components of ACC. Except at 2 N1, a significant

difference was noticed for /sa/ stimulus presented through the insert receiver. The reason could be the circumference of the head size, which is relatively smaller in females. The results appear to correlate with the finding of head size as a basis of gender difference in the latency,[35] which influences the volume conduction and takes less time to reach the generation sites.

Though the physiological hormonal changes during the menstrual cycle might be a factor for the reduced and varied latencies, this was not accounted for at the time of recording ACC. Yadav et al.[36] investigated auditory processing at the cortical level using CAEPs in the stages of menstrual cycle. Estrogen and progesterone hormonal changes in the stages of menstrual cycle affect the synaptic transmission at the auditory association areas by modulating the secretion of gamma amino butyric acid (GABA). The mid-luteal (17th-22th day) stage, a peak secretion of progesterone hormone, may decrease the sensitivity of neurons and blunt the estrogen potentiated GABA release leading to the earlier latencies of CAEP. This result was substantiated by yet another study on the effect of menstrual hormones at the brainstem level. The finding suggests that the latencies of auditory brainstem response showed faster conduction during mid-luteal phase.[37]

Further, the amplitude of all the components of ACC are noted to be larger in female participants than their male counterparts for both the stimuli, presented through each of the transducers, but found significant in the amplitude of 2P2 alone. In addition to the head circumference, a more rapid myelination, an increased synaptic efficiency in females[38] might have led to reduced latency and larger amplitude. Apart from the anatomical differences, physiological and cognitive processes may be involved. Stockard et al.[39] reported that the decrease in central conduction time with a relatively increased body temperature and hormonal related nervous conduction[40] in females, might have resulted in reduced latency and larger amplitude of ACC. Further greater frontal brain activation was noticed in verbal intelligence scores and memory retrieval in females than males.[41]

Table 3. Results of two-way mixed analysis of variance (ANOVA) for latency (ms) of each component of acoustic change complex.

Effects	Parameters	N1		P2		2N1		2P2	
		F-ratio	P	F-ratio	P	F-ratio	P	F-ratio	P
Interaction effects	Stimuli* gender	0.17	0.67	1.99	0.16	0.32	0.57	0.38	0.53
	Transducers* gender	3.50	0.07	0.02	0.87	2.39	0.13	2.23	0.14
	Stimuli* transducer	0.06	0.80	0.09	0.92	0.07	0.79	3.22	0.84
	Stimuli* transducer* gender	0.48	0.49	1.73	0.20	1.72	0.20	1.63	0.21
Main effect (between subject)	Gender	2.99	0.09	0.06	0.93	10.56	0.00*	1.99	0.16
Main effect (within subject)	Stimuli	3.64	0.06	2.11	0.15	36.08	0.00*	0.20	0.65
	Transducers	1.73	0.19	3.17	0.08	140.12	0.18	0.69	0.41

*Significant at 0.01.

Table 4. Results of two-way mixed analysis of variance (ANOVA) for amplitude (µV) of each component of acoustic change complex.

Effects	Parameters	N1		P2		2N1		2P2	
		F-ratio	P	F-ratio	P	F-ratio	P	F-ratio	P
Interaction effects	Stimuli* gender	0.31	0.57	1.12	0.29	2.15	0.15	5.00	0.09
	Transducers* gender	0.33	0.85	0.38	0.54	0.04	0.84	0.04	0.82
	Stimuli* transducer	0.47	0.49	1.76	0.19	0.55	0.46	0.24	0.62
	Stimuli* transducer* gender	4.50	0.06	0.51	0.47	0.23	0.88	0.38	0.53
Main effect (between subject)	Gender	6.97	0.01*	0.23	0.63	2.67	0.11	10.27	0.00*
Main effect (within subject)	Stimuli	1.14	0.29	0.59	0.44	0.81	0.37	1.56	0.22
	Transducers	2.78	0.10	9.73	0.07	0.41	0.84	2.09	0.16

*Significant at 0.01.

Conclusions

The results of this study show that ACC is a sensitive index in detecting the change in the stimulus. The mean latency of onset response was earlier and amplitude was larger for /sa/ than /si/ stimulus presented through either transducer. This is due to the faster rise time and larger energy at the onset portion of /sa/ stimulus. Further, transition portion of latency was earlier and amplitude was larger for /sa/ than /si/ stimulus presented through either transducer. However, significant difference was found in 2N1 component alone. This could be due to the rapid rate of formant transition in /sa/ than /si/ stimulus and conduction volume.

In case of transducers, there was no significant difference in the latency and amplitude of ACC between insert earphone and loudspeaker for both the stimuli. This could be due to the calibration factor that ensured same levels of presentation through the transducers. Also the spectra of stimuli delivered were within the frequency responses of the transducers. Further, the mean latency of ACC was shorter for insert earphone than loudspeaker. This could be due to transmission delay of 2.8 ms from the loud speaker. In case of mean amplitude, transition portion of response are larger for loudspeaker than insert earphone for each stimulus, as the resonance frequency was obscured by insertion depth of insert earphone. However, the mean of the amplitude of N1 component alone was larger for /sa/ stimulus presented through insert earphone, in male group.

Among gender, the mean latencies were earlier and amplitudes were larger in all components of ACC in female than male participants due to difference in anatomical structure and physiological process. This difference was significant for the 2N1 in latency alone and N1 and 2P1 in the amplitudes of ACC. However in the amplitude of N1 and 2P1 is larger in female than their male counterpart.

Thus in the present study, the ACC was elicited by a change in an ongoing acoustical stimuli as in /sa/ and /si/. The effect of stimulus type, sound transducer, and gender of the participant on the amplitudes and latencies of the ACC was investigated. The results revealed that stimuli and gender have an effect on the components of ACC but not the type of transducers.

Implication of the study

The study suggests that ACC is a sensitive cortical evoked potential to determine the spectral changes in an ongoing stimulus. This can be recorded with insert earphone and loudspeaker. The study finding of this can be used in determining the capacity of impaired auditory pathway to detect the subtle spectral change in the stimulus at the level of the auditory cortex. Since the response is reliably recorded using loudspeaker, the ACC can be studied in individuals using a hearing device. Further, in individuals with varying contours of hearing loss, the integrity of neurons at the auditory cortex can be investigated. The amount of compensation/support received from hearing aid with varying contours of hearing loss can be compared by recording ACC in unaided and aided conditions.

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