Acoustic Change Complex in Native Speakers of Tonal and Non-Tonal Languages

[1]Suma Chatni & [2]Sandeep Maruthy

Abstract

The present study focused on the effect of experience-dependent plasticity on the ACC and to explore the hemispheric specialization of lexical pitch processing. The purpose was to determine whether the spectral change being lexical or non-lexical, influences the characteristics of ACC and to analyze the cortical asymmetry (if any) in the generation of ACC. To examine this, ACCs were recorded in native speakers of tonal and non-tonal languages, from 3 different electrode sites. The latency and amplitude of ACC were compared between the two groups and across the three electrode sites. Results revealed that the differences between the groups were not significant. The ACCs were symmetric across the two hemispheres. Hence, it can be inferred that ACC is not influenced by lexicality of the stimulus.

Key words: *ACC, tonal language, experience-dependent plasticity, hemispheric asymmetry*

Introduction

Acoustic Change Complex (ACC) is a cortical auditory evoked potential (P1-N1-P2) elicited by a change within an ongoing sound stimulus and is reported to be most robust at the vertex (Martin & Boothroyd, 1999). The ACC is likely a simple change detection response (Hillyard & Picton, 1978; Picton, Alain, Otten, Ritter & Achim, 2000) that results from the activation of new neural elements together with the deactivation of others (Martin & Boothroyd, 1999; 2000).

Initial research about ACC was conducted by Kaukoranta, Hari and Lounasmaa (1987) wherein they recorded neuromagnetic responses of the human auditory cortex to vowel onset after fricative consonants. The results indicated that the vowel onset after voiceless fricative consonants evoked a prominent response in the supra-temporal auditory cortex. They concluded that it might reflect feature detection essential for further speech processing.

Jones, Longe and VazPato later in 1998, tried to examine the cortical auditory evoked potentials to complex tones changing in pitch and timbre as a possible means for investigating higher auditory processes, in particular, those concerned with streaming and auditory object formation. They concluded that the N1 evoked by a sudden change in pitch or timbre was more posteriorly distributed than the N1 at the onset of the tone, indicating at least partial segregation of the neuronal populations responsive to sound onset and spectral change.

Ostroff, Martin and Boothroyd (1998) investigated whether the evoked potential got in response to a complex naturally produced speech syllable would include the individual contributions from the acoustic events contained in the constituent phonemes. They recorded cortical potentials N1 and P2 using three naturally produced speech stimuli, [sei], [s] and [ei]. They reported that the response to [s] as well as to [ei] had N1 and P2 components with latencies, in relation to sound onset, appropriate to cortical onset potentials. They also observed that the vowel onset response had reduced amplitude in the response to the complete syllable. They concluded that the response to [ei] from [s] in the syllable reflected changes of cortical activation caused by amplitude or spectral change at the transition from consonant to vowel. They suggested that the auditory cortical evoked potential to complex, time-varying speech waveforms can reflect features of the underlying acoustic patterns.

Martin and Boothroyd (1999) found that it was possible to elicit the ACC solely with the change in periodicity with all the other parameters kept constant. Also, Tremblay, Friesen, Martin and Wright (2003) found out that the auditory cortical evoked potentials elicited by naturally produced speech sounds were reliably recorded in individuals. They concluded that given the reliability of the response, this response has potential application to the study of neural processing of speech in individuals with communication disorders as well as changes over time after various types of auditory rehabilitation.

Research has shown that ACC can not only be reliably recorded in normal hearing individuals but also in subjects with sensori-neural hearing loss with (Tremblay, Billings, Friesen & Souza, 2006) and

[1] E-mail: sumachatni@gmail.com; [2]Lecturer in Audiology, E-mail: msandeepa@gmail.com

without hearing aids (Tremblay, Kalstein, Billings & Souza, 2006) and cochlear implants(Friesen & Tremblay, 2006). To add to its advantages, its occurrence correlates well with the behavioral discrimination of intensity (Martin & Boothroyd, 2000) and frequency (Danilkina, Wohlberedt & Hoppe, 2009). It is easy to record and its amplitude is relatively high, in turn requiring less number of averages and being less time taking. Hence, ACC has all those essential characteristics to become a potential clinical tool.

Considering these clinical advantages, it is important to further understand whether ACC is purely exogenous, or is endogenous, influenced by linguistic and cognitive factors. Till date, however, studies have not focused on the effect of linguistic factors on ACC. That is, if the change in the spectra that can elicit an ACC is phonemic in a particular language, whether the characteristics of ACC change. Considering that the latency of ACC is more than 200 ms, the linguistic and the cognitive factors are expected to play a role in the generation of ACC. This needs to be experimentally investigated. The present study was an attempt in this direction where influence of linguistic factors like semantics on ACC was studied. Hence, the primary objective of the study was 'to compare the ACC elicited from native speakers of a tonal language and the non-tonal language speakers'.

Cross-language neuroimaging (Gandour, Wong, Hsieh, Weinzapfel, Van Lancker & Hutchins, 2000; Hsieh, Gandour, Wong & Hutchins, 2001), behavioral (Wang, Behne, Jongman & Sereno, 2004), hemisphere lesion (Gandour, 1998) and neuropsychological (Gandour, 1998) studies reveal a leftward specialization for native speakers of tonal languages. However, the MMN response to lexical pitch has been shown to be lateralized to the right hemisphere in native speakers (Luo, et al., 2006), a finding that conflicts with the report that MMN responses to native categories show a leftward asymmetry (Näätänen, Paavilainen, Rinne & Alho, 2007). Hence, the results of hemispheric asymmetry in the processing of lexical tone are equivocal. Also, there is a dearth of studies on the hemispheric specialization of lexical tone using ACC. Thus, the secondary objective of the present study was to investigate the hemispheric specialization in the processing of lexical tones in the native speakers of tonal and non-tonal languages.

Method

Participants

ACC was recorded from two groups of participants; Group I had 16 participants (nine males & seven females), who were native speakers of Manipuri, a tonal language spoken in the state of Manipur, India. All the participants in this group were born and raised in Manipur and were Manipuri-Hindi bilinguals. Group II on the other hand had 17 (nine males & eight females) native speakers of Kannada, a non-tonal language spoken in the state of Karnataka, India. A detailed history confirmed that the participants in the Group II were never been exposed to any tonal language.

The participants in both the groups were in the age range of 18 to 28 years (*M*ean of 21 years 10 months). They had pure tone thresholds within 15 dBHL at octave frequencies between 250 Hz and 8000 Hz and, normal middle-ear function. Normal middle ear function was ensured through type-A tympanogram and the presence of bilateral acoustic reflexes. They did not have complaint of any neurological problem. They were screened for central auditory processing disorder through a detailed case history and on speech perception in noise (SPIN) test. All of them obtained a score of >60% in both the ears on SPIN test. A written consent was taken from all the participants prior to their inclusion.

Test Stimuli

Three monosyllabic words of Manipuri were used to record ACC. Of the three, two words were phonetically similar but differed in their tone. As the tonal variation was lexical for Manipuri speakers and not for Kannada speakers, this stimulus pair could test the objective of the study. The two tonal variations of the stimulus pair are designated as /ḷaI-1/ and /ḷaI-2/ which mean 'flower' and 'stay' respectively. The third monosyllabic word used was /tuI/ which meant 'fall'.

The three words were naturally produced by an adult female, who was a native speaker of Manipuri. The utterances were digitally recorded by a unidirectional microphone in a sound treated room using Praat software (version 5.1.31) at a sampling frequency of 44,100 Hz and 16 bit digitization. The durations of /ḷaI-1/, /ḷaI-2/ and /tuI/ were 358, 379 and 288 ms respectively. To avoid an abrupt offset, the amplitude was reduced to zero over the last 10 ms using raised cosine function. The stimuli were normalized to maintain uniform peak amplitude across all the three stimuli, using Adobe audition software (version 3.0). They were then converted to STM file, using Intelligent Hearing System stimulus conversion software. The time domain waveform and the spectrogram of the three stimuli are shown in Figure 1-

3. The spectral and temporal parameters of the three stimuli have been listed in Table 1.

Instrumentation

Audiological equipments were required for the preliminary audiological evaluation as well as for recording ACC. A Madsen Orbiter-922 type I audiometer with TDH-39 headphones and B-71 bone vibrator, was used to estimate the air- and bone-conduction thresholds respectively and to carry out speech audiometry. A calibrated Grason StadlerInc-Tympstar immittance meter was used to rule out middle ear pathology. Intelligent Hearing System-Smart EP (version 2.39) evoked potential system was used for recording ACC. A computer with Praat software (version 5.1.31) and Adobe Audition (version 3.0) was used to record and edit the speech stimuli.

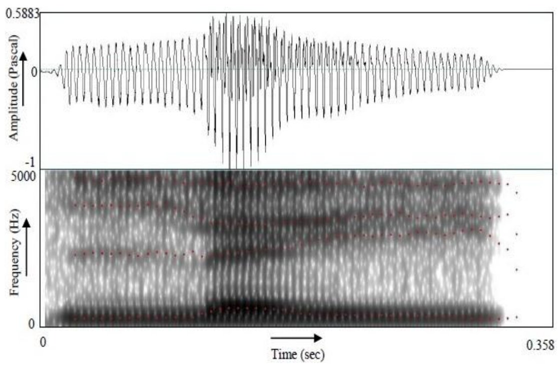

Figure 1: Time domain waveform and the spectrogram of /ḷaI-1/.

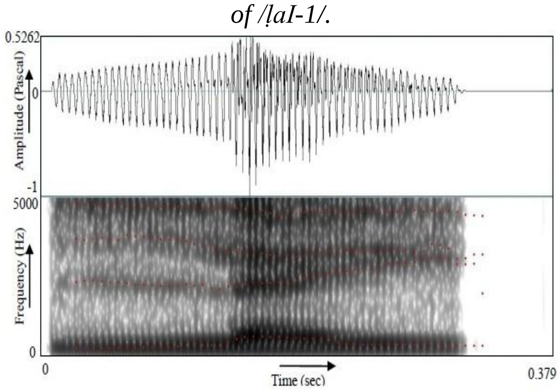

Figure 2: Time domain waveform and the spectrogram of /ḷaI-2/.

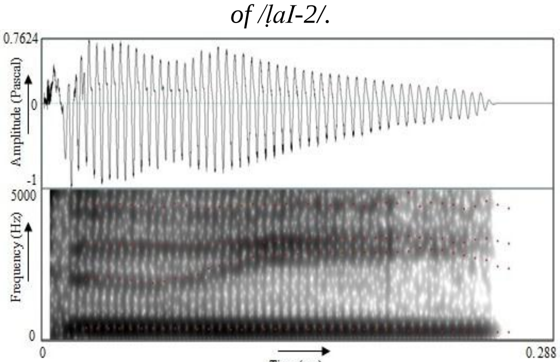

Figure 3:Time domain waveform and the spectrogram of /tuI/.

Test Environment

Recording of the test stimuli as well as the audiological testing were carried out in an acoustically treated room where noise levels were within permissible limits (ANSI S3.1, 1991). The room was also electrically shielded. The puretone audiometry was carried out in a double room set up while the electrophysiological testing was done in a single room set up.

Preliminary Evaluation

Prior to the actual test procedure, participants underwent the following evaluations to ensure that they fulfilled all the selection criteria. It started with a detailed case history probing into their past or present history of otological and neurological conditions, which was followed by pure-tone audiometry, speech audiometry and tympanometry. Pure tone thresholds were obtained at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction using modified Hughson-Westlake procedure (Carhart & Jerger, 1959).

Speech recognition threshold (SRT) was found using Manipuri polysyllabic word list developed and standardized by Devi and Vyasamurthy (1985) for Group I and Kannada spondee word list for Group II. The speech identification scores (SIS) were obtained at 40 dBSL (ref: SRT) using Manipuri monosyllabic word list developed and standardized by Devi and Vyasamurthy (1985) for Group I and phonemically balanced word list in Kannada developed by Yathiraj and Vijayalakshmi (2005) for Group II. Tympanometry using 226 Hz probe tone was carried out to rule out the presence of any middle ear pathology. Ipsilateral and contralateral reflexes were obtained at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Test Procedure

The actual test procedure involved the recording of ACC. It was recorded using silver chloride (AgCl) electrodes placed at Cz, C3, and C4, referenced to the tip of the nose. An electrode at Fpz served as ground. Vertical eye movements (EOG) were recorded between two electrodes placed above and below the right eye. Trials with electrical activity that exceeded 160 μV were excluded from averaging, in order to eliminate the likelihood of response contamination with eye blink artifacts. The sites of electrode placement were prepared with skin preparation gel and the electrodes were held in their respective positions with a plaster. Absolute electrode impedances were maintained below 5 kΩ and interelectrode impedances were less than 2 kΩ in order to facilitate the recording.

After preparation, subjects were made to relax on a reclining chair and watch a silent, closed-captioned movie. Each of the three stimuli was presented in two blocks, yielding a total of six blocks. In each block, the stimulus-locked responses were averaged for 350 presentations. Therefore, total number of presentations of each stimulus was 700. The order of presentation was randomized to eliminate the possible order effect. The stimulus and acquisition parameters used to record ACC are given in Table 2.

Table 1: .Spectral and temporal parameters of the test stimuli

Parameter		/ḷaI-1/	/ ḷaI-2/	/t̪uI/
Total duration (ms)		358	379	288
F_2 transition	Onset (ms)	119	132	62
	Offset (ms)	207	258	125
	Extent (Hz)	626	808	911
F_3 transition	Onset (ms)	88	101	NS
	Offset (ms)	119	139	NS
	Extent (Hz)	567	396	NS

Note: **NS**-No significant transition

Table 2: Stimulus and acquisition parameters used to record ACC

Stimulus Parameters	
Type	Natural monosyllabic words /ḷaI-1/, / ḷaI-2/ and /t̪uI/
Transducer	EARtone 3A insert earphones
Rate	1.1/s
Intensity	70 dB SPL
Polarity	Alternating
Mode of presentation	Binaural
Acquisition parameters	
Electrode montage	Vertical
Amplification	EEG channel 25,000 EOG channel 5,000
Analysis time	800 ms
Filters	1-100 Hz
Pre-stimulus time	100 ms
Sweeps	350

Response Analysis

The two recordings of each stimulus were examined for replicability. Only the replicable waves were considered for analysis. If replicable, they were averaged and the averaged wave was analyzed by two experienced audiologists to mark the N1-P2 complex in the second LLR as shown in the Figure 4. The responses were analyzed in terms of their latency, peak-to-peak amplitude and the morphology.

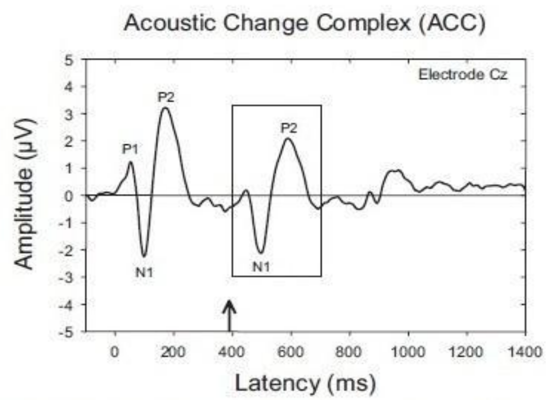

Figure 4: ACC recorded for the 800 ms stimulus /ui/ at Cz,. Courtesy of Martin and Boothroyd (2000)

Results

In the present study, three independent variables; group, stimuli and the channel were taken and their influence on the dependent variables; parameters of ACC (latency & amplitude) was studied. Latency of N1' and P2' and peak to peak amplitude of N1'-P2' were the target parameters analyzed. The statistical analysis was carried out using Statistical Package for Social Sciences (SPSS) (Version 17).

Descriptive statistics was applied to obtain the mean and standard deviation of the peak latency of N1' and P2' and peak to peak amplitude of N1'-P2' elicited by the three stimuli in the two groups of participants. Two-way repeated measure ANOVA was administered to find out the significant main effect of stimulus and channel on the latency and amplitude of ACC between groups, and within group in instances of group interaction. Bonferroni's post hoc test was used for pair-wise comparison in instances where there was a significant main effect of stimuli and channel. Independent t-test was done for P2' latency to determine which channel and which stimuli led to difference between the groups. Wherever there was interaction of the group with other 2 independent variables, repeated measures ANOVA followed by Bonferroni's post hoc was carried out separately for

Table 3: Mean and Standard Deviation (SD) of N1' and P2' latencies recorded for three Manipuri words, from three different electrode sites in the two groups of subjects

Stimulus	Group	Wave	Latency (ms)					
			Cz		C3		C4	
			Mean	S.D.	Mean	S.D.	Mean	S.D.
/ḷaI-1/	I	N1'	225.30	12.38	225.50	12.40	225.10	12.86
		P2'	280.30	9.67	281.20	10.93	280.60	9.59
	II	N1'	217.90	10.60	218.09	10.44	217.34	9.49
		P2'	273.47	10.62	273.94	10.44	273.85	10.71
/ḷaI-2/	I	N1'	235.40	12.46	236.30	12.05	235.60	12.56
		P2'	290.90	15.90	291.50	15.84	291.80	16.50
	II	N1'	231.71	13.41	231.71	13.43	231.52	13.08
		P2'	284.98	13.63	284.61	13.58	285.08	13.74
/t̪uI/	I	N1'	232.50	15.43	232.60	15.20	232.52	15.18
		P2'	297.30	17.52	298.80	18.40	298.50	18.19
	II	N1'	230.21	15.96	229.83	16.61	228.80	15.59
		P2'	283.67	12.95	283.76	13.26	283.29	12.57

each group to ascertain the significant main effect of stimulus and channels on the latency and amplitude of the ACC.

The mean and standard deviation values for N1' and P2' latency obtained in both the groups for the three stimuli, across the three channels were calculated and were as given in Table 3.The following trends could be observed in the mean data. The mean latencies of N1' for all the electrode sites and for all the stimuli were prolonged for Group I than those recorded from Group II and the difference in the mean N1' latency between the two groups was maximum for /ḷaI-1/, followed by /ḷaI-2/ and /t̪uI/, irrespective of the electrode site. On the other hand, the mean latencies of P2' for all the electrode sites and for all the stimuli were prolonged for Group I than those recorded from Group II and the difference in the mean P2' latency between the two groups was maximum for /t̪uI/, followed by /ḷaI-1/ and /ḷaI-2/, irrespective of the electrode site.

In the present study, channel and stimuli were repeating variables while group was an independent variable. Hence, two-way repeated measure ANOVA was carried out for stimulus and channel taking group as independent variable. Results of the test are discussed under 2 headings: *Results of latency of N1' and P2'* and the *Results of amplitude of ACC.*

Results of Latency of ACC

Two-way repeated measure ANOVA (3 stimuli & 3 channels) was done separately for N1' and P2' latency to test the statistical significance of mean differences observed across the 3 stimuli and 3 channels. The output of ANOVA showed that there was a significant main effect of the stimulus on both N1' and P2' latency. Further, there was a significant main effect of channel and, channel to group interaction on the latency of P2'. None of the interactions were significant in the latency of N1'. Results are given in Table 4.

Since the outcome of two-way repeated measure ANOVA of P2' latency indicated significant main effect of stimulus, pair-wise comparison of the stimuli was carried-out using Bonferroni's post-hoc test. It was shown that there was significant difference between the stimuli /ḷaI-1/ and /tuI/ across all the channels in Group I. Along with the difference between /ḷaI-1/ and /t̪uI/, Group II also demonstrated a significant difference between /ḷaI-1/ and /ḷaI-2/.

Because the results of two-way repeated measure ANOVA of N1' latency showed only the significant main effect of stimulus and no significant interactions, pair-wise comparison was directly tested using Bonferroni's post-hoc test. Results revealed a statistically significant difference in N1' latency between /ḷaI-1/ and /ḷaI-2/ and between /ḷaI-1/ and /t̪uI/. However, difference was not significant between /ḷaI-2/ and /t̪uI/.

The grand mean waveforms of the ACC evoked by /ḷaI-1/ and /ḷaI-2/ recorded at Cz in Group II have been displayed in Figure 5 and those evoked by /ḷaI-1/ and /t̪uI/ recorded at Cz in Group II have been shown in Figure 6.

Table 4: Two-way repeated measures ANOVA for stimulus and channel with group as independent variable for N1' and P2' latency

Measure	Variable	F	df (error df)
N1' latency	Stimulus	9.046*	2 (62)
	Channel	1.532	2 (62)
	Stimulus X Group	0.314	2 (62)
	Channel X Group	0.726	2 (62)
	Stimulus X Channel	0.471	4 (124)
	Stimulus X Channel X Group	0.614	4 (124)
P2' latency	Stimuli	10.671*	2 (62)
	Channel	4.285*	2 (62)
	Stimulus X Group	1.065	2 (62)
	Channel X Group	3.405*	2 (62)
	Stimulus X Channel	1.118	4 (124)
	Stimulus X Channel X Group	0.896	4 (124)

*p<0.05

However, in the results of P2' latency, there was significant interaction of group with the channel. Hence, the effect of channel on P2' latency was tested using repeated measures ANOVA and subsequent Bonferroni post-hoc test, taking each group seperately. The results of post-hoc test showed that there was no significant differences in any of the pairs of channels. Hence, the main effect of channel was probably due to the interaction of the group effect. The group effect was tested on independent t-test and the results are given in Table 5.

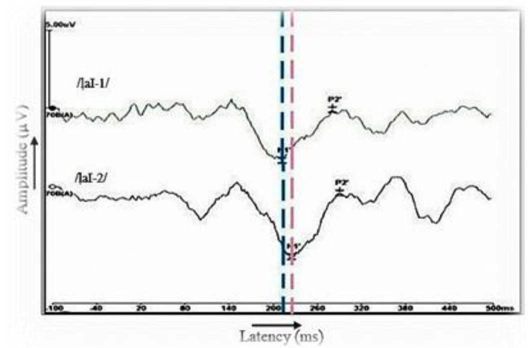

Figure 5: The Group II grand mean waveforms of the ACC evoked by /ḷaI-1/ and /ḷaI-2/ recorded at Cz.

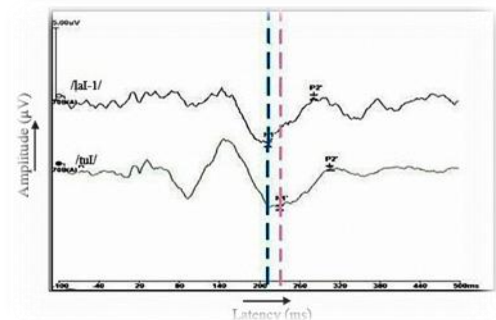

Figure 6: The Group II grand mean waveforms of the ACC evoked by /ḷaI-1/ and /t̪uI/ recorded at Cz.

Table 5: Results of independent t-test for P2' latency between the two groups across stimuli and channels

Stimulus	Channel	t	df
/ḷaI-1/	Cz	1.927	31
	C3	1.950	31
	C4	1.899	31
/ḷaI-2/	Cz	1.149	31
	C3	1.343	31
	C4	1.274	31
/t̪uI/	Cz	2.551*	31
	C3	2.704*	31
	C4	2.807*	31

*p<0.05

The independent t-test revealed significant differences between the groups for the stimulus /t̪uI/ across all the three channels. No differences were noted between the two groups when the responses were elicited by other two stimuli in any of the channels. The waveforms of the ACC evoked by the stimulus /t̪uI/

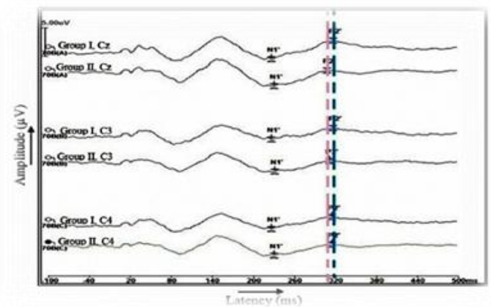

Figure 7: The Grand mean waveforms of the ACC evoked by /tuI/ in both groups at Cz, C3 and C4.

in both groups at Cz, C3 and C4 have been displayed in Figure 7.

Results of Amplitude of ACC

The mean and standard deviation values for peak to peak amplitude of N1'-P2' obtained in both the groups for the three stimuli, across the three channels were calculated and were as given in Table 6.

The mean amplitude of N1'-P2' for all the electrode sites and for all the three stimuli was higher for Group II than those recorded from Group I and the difference in the mean N1'-P2' amplitude between the two groups was highest for /ḷaI-2/, followed by /t̪ui/ and /ḷaI-1/, except for Cz where the difference in the mean amplitude of N1'-P2' between the groups was slightly greater for /ḷaI-1/ than /t̪uI/, highest being for /ḷaI-2/.

Table 6: Mean and Standard deviation (SD) of the peak to peak amplitude of N1'-P2' recorded for three Manipuri words, from three different electrode sites in the two groups of subjects

Amplitude (N1'-P2') (µV)					
Cz		C3		C4	
Mean	S.D.	Mean	S.D.	Mean	S.D.
3.42	1.02	2.67	0.88	2.73	1.09
3.68	1.42	2.91	1.01	2.82	1.14
3.63	1.07	2.76	1.09	2.90	0.87
4.09	1.90	3.51	1.50	3.55	1.59
4.18	1.47	2.98	1.19	3.13	1.09
4.42	1.66	3.37	1.12	3.57	1.25

Two-way repeated measure ANOVA (3 stimuli & 3 channels) was done for N1'-P2' amplitude to test the statistical significance of mean differences observed across the 3 stimuli and 3 channels. Results are displayed in Table 7.

Table 7: Two-way repeated measure ANOVA for stimulus and channel with group as independent variable for N1'-P2' amplitude

Variable	F	df (error df)
Stimuli	2.853	2 (62)
Channel	100.388*	2 (62)
Stimulus X Group	0.394	2 (62)
Channel X Group	0.549	2 (62)
Stimulus X channel	2.040	4 (124)
Stimulus X Channel X Group	0. 486	4 (124)

*p<0.05

The result of ANOVA showed that there was a significant main effect of the channel on N1'-P2' amplitude. There were no significant interactions evidenced between the independent variables. Because the results of two-way repeated measure ANOVA of N1'-P2' amplitude showed significant main effect of channel and no significant interactions, Bonferroni's post-hoc test was directly adopted for pair-wise comparison. The results revealed a statistically significant difference in N1'-P2' amplitude recorded at Cz and C3 and also between Cz and C4. However, nosuch differences were noted between C3 and C4.The Group II mean waveforms of ACC recorded at Cz and C3 and, Cz and C4 sites have been displayed in Figure 8 and Figure 9 respectively.

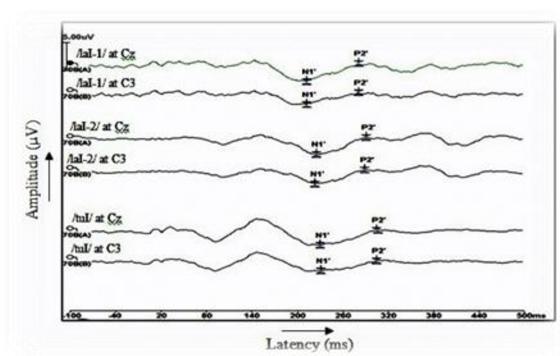

Figure 8: The Group II mean waveforms of the ACC recorded at Cz and C3 for the three stimuli.

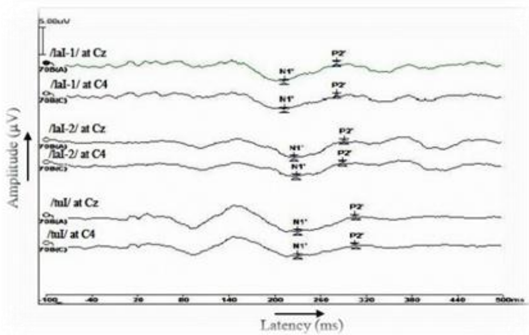

Figure 9: The Group II mean waveforms of the ACC recorded at Cz and C4 for the three stimuli.

Discussion

The present study was started with a null hypothesis that there is no difference between the ACC recorded from the tonal language speakers and the non-tonal language speakers. The results of the present study don't support this null hypothesis. This is because there was significant group difference in the latency of P2' of ACC when elicited by /t̪uI/. Specifically, the Group I participants had prolonged latencies and reduced amplitudes compared to their Group II counterparts.

It was assumed that comparing the ACC measured between the two groups is an approximation of comparing the responses elicited using semantic and phonetic stimuli. The P2' observed in the ACC occurs in the same latency following stimulus onset and is similar in appearance to the well-known cortical response P2 which occurs at approximately 160 ms after stimulus onset. Hence, it was possible to support the present finding by the studies involving the cortical P2 response. Henkin, Kishon-Rabin, Gadoth and Pratt (2002) compared the cortical auditory evoked potentials elicited by phonetic and semantic stimuli. They used nonmeaningful consonant-vowel-consonant monosyllabic words as phonetic and six meaningful monosyllabic consonant-vowel-consonant words as the semantic set of stimuli. They reported prolonged P2, N2 and P3 latencies characterizing semantic processing compared to phonetic processing. They concluded that semantic processing was significantly different from phonetic processing in latency and amplitude. Results of the present study are in agreement with several of the earlier studies (Henkin, Kishon-Rabin, Gadoth & Pratt, 2002; Kayser, Tenke & Bruder, 1998; Henkin, et al., 1999; Putter-Katz, Kishon-Rabin, Sachartov, Gadoth & Pratt, 1999, among others). In these studies prolonged latencies have been attributed to greater task difficulty and decreased neural synchrony.

Based on the present findings, it can be inferred that the prolonged latencies obtained for the Group I could be because a single mechanism in the auditory cortex might be involved in general processing of acoustic features for speech and non-speech stimuli, but may require further processing for meaningful linguistic stimuli. Thus, the delay observed in Group I in the processing of stimuli could be mainly due to the difference in the extent or stages of processing involved in the two types of stimuli.

However, no group differences were observed for other two stimuli: /ḷaI-1/ and /ḷaI-2/. If ACC was to be influenced by meaning of the stimulus, the group differences should have been present for /ḷaI-1/ and /ḷaI-2/ as well. The presence of group differences only in /t̪ui/ weakens the conclusion that the ACC is influenced by the lexical factors.

Also, the group differences in terms of N1' latency and peak to peak amplitude of N1'-P2' failed to reach statistical difference. Similar findings were obtained by Henkin, et al., (2002) regarding N1 latency and amplitude which is speculated to have similar cortical origins as N1' of ACC. Both are observed to occur for stimulus onset, and are similar in appearance and latency. Henkin, et al., (2002) reported that N1 latency and amplitude did not differ between the phonetic and semantic tasks. This finding is not surprising and is consistent with N1 being an obligatory stimulus onset response, reflects the registration of stimulus in the cortical areas rather than lexical differences between stimuli (Näätänen & Picton, 1987).

Studies conducted utilizing FFR have reported stronger pitch representation and smoother pitch tracking in native speakers of tonal languages (Krishnan, Xu, Gandour & Cariani, 2005; Krishnan, Gandour & Bidelman, 2010). Whereas, the results of the present study revealed prolonged latencies and reduced amplitudes in the native speakers of tonal language. FFR, on one hand is analyzed on the spectral domain whereas ACC is analyzed in the temporal domain. Also, the generators of the two responses are at two different levels. Hence, the results of the two groups of studies cannot be directly compared.

Furthermore, the brainstem mainly encodes the acoustic parameters such as F_o and the harmonics of the incoming acoustic stimulus. On the other hand, the auditory cortex takes up the complex task of deciding whether the incoming stimulus is semantic or phonetic, whether it is relevant to the individual or not.

The results of the present study also conflicted with the research done using cortical auditory evoked potentials in native speakers of tonal and non-tonal languages

(Chandrasekaran, Krishnan & Gandour, 2007; Chandrasekaran, Krishnan & Gandour, 2009). They reported larger MMN responses in speakers of tonal languages. Most of them have been conducted on the native speakers of Chinese. However, the frequency of routine usage of lexical tones in Manipuri may not be same as that in Chinese and the extent of tonality between the two languages may vary. Hence, the results of Chandrasekaran, Krishnan and Gandour (2007) and Chandrasekaran, Krishnan and Gandour (2009) cannot be looked at the same level with the present study. Also, the above authors have recorded MMN by presenting the two variations of tone present in that particular tonal language. So the comparison of the two tonal variations of the stimuli might yield larger responses in tonal language speakers than by just presenting a stimulus having lexical pitch when compared to non-tonal language speakers. In other words, the procedures used to elicit ACC and MMN and the generators are different. In the present study ACC was not enhanced in the native speakers of Manipuri compared to the native speakers of Kannada. This finding supports that ACC is not influenced by the meaning association to the stimulus, unlike MMN.

The second objective of the study was to evaluate the cortical asymmetry (if any) in the generation of ACC, in native speakers of tonal and non-tonal language. Two of the stimuli selected, /ḷaI-1/ and /ḷaI-2/ were phonetically same and differed only in the tone which conveyed lexical information only for the Manipuri speakers. Since the stimuli selected had lexical tone embedded in them, they would serve as perfect tools to study the cerebral asymmetry in speakers of a tonal language. The hypothesis was that there won't be any significant cerebral asymmetry noted in tonal and non-tonal language speakers. The differences between the channels were only evident for the amplitude of ACC. Responses at Cz were significantly different compared to C3 and C4, while, no differences were revealed between the channels C3 and C4. Among the channels, it was observed that Cz had the highest amplitude. This is in accordance with the other studies (Tremblay, Friesen, Martin & Wright, 2003; Martin & Boothroyd, 2000) who have also reported maximum amplitude at Cz. N1 has multiple generators in the primary and secondary auditory cortex (Näätänen & Picton, 1987; Näätänen, 1992). Hence when recorded from the vertex, there is a possibility of an increase in the summed up amplitude from all sources.

The significant channel effect of the ACC was not influenced by the group differences. If ACC were to be influenced by lexicality, group effect would have influenced the channel effect. Also, there were no significant differences between the responses measured from C3 and C4, which also indicates that ACC is not affected by lexical factors.

Probably, the results may also depend on the extent of daily usage or experience with the stimuli used by the Group I participants. To conclude, more studies of this kind are needed in speakers of Manipuri language and by using multiple scalp electrodes to notice even the minor differences between the hemispheres in processing of lexical pitch.

Conclusions

The differences between the groups were not significant across all the stimuli. Hence, it can be inferred that ACC is not influenced by the lexicality of the stimulus. As the amplitude and latency of ACC were symmetric between the two hemispheres, it further supports the finding that ACC is not endogenous. A more controlled study with a large number of subjects is suggested. The study threw light on the nature of ACC which has implications for future research however it further needs to be authenticated before being used for clinical purposes.

Acknowledgements

We are thankful to Director, All India Institute of Speech and Hearing for permitting to conduct this project and for providing the infrastructure.

References

American National Standards Institute (1991). *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms* (ANSI S3.1.1991). New York: ANSI.

Carhart, R., & Jerger. J. (1959). Preferred method for clinical determination of puretone thresholds. *Journal of Speech and Hearing Disorders, 24,* 330-345.

Chandrasekaran, B., Krishnan, A., & Gandour, J. T. (2007). Mismatch negativity to pitch contours is influenced by language experience. *Brain Research*, 148-156.

Chandrasekaran, B., Krishnan, A., & Gandour, J. T. (2009). Relative influence of musical and linguistic experience on early cortical processing of pitch contours. *Brain & Language*, *108*, 1–9.

Danilkina, G., Wohlberedt, T., & Hoppe, U. (2009).The Acoustic Change Complex and Frequency Discrimination for Subjects with Normal Hearing. *Arquivos de Medicina*, *23*, 198.

Devi, T. E., & Vyasamurthy, M. N. (1985).*Development and standardization of speech test materials in Manipuri language.* Unpublished Master's dissertation submitted in part fulfilment of M.Sc. to the University of Mysore.

Friesen, L. M., & Tremblay, K. L. (2006). Acoustic Change Complexes Recorded in Adult Cochlear Implant Listeners. *Ear & Hearing, 27,* 678–685.

Gandour, J. (1998). Aphasia in tone languages. In Coppens P, Basso A, Lebrun Y, editors. *Aphasia in atypical populations* (pp.117–141), Hillsdale, New Jersey: Lawrence Erlbaum.

Gandour, J., Wong, D., Hsieh, L., Weinzapfel, B., Van Lancker, D., & Hutchins, G. D. (2000). A cross-linguistic PET study of tone perception. *Journal of Cognitive Neuroscience, 12*, 207–222.

Henkin, Y., Kishon-Rabin, L., Gadoth, N, & Pratt, H. (2002). Auditory Event-Related Potentials during Phonetic and Semantic Processing in Children. *Audiology Neurootology, 7*, 228–239.

Henkin, Y., Kishon-Rabin, L., Sachartov, E., Kiviti, S., Gadoth, N, & Pratt, H. (1999). *ERPs associated with phonological and semantic processing in idiopathic generalized epilepsy of childhood.* Presented in 16th International Evoked Response Audiometry Study Group Biennial Symposium, Tromsö.

Hilyard, S. A., & Picton, T. W. (1978). ON and OFF components in the auditory evoked potential. *Perception and Psychophysics, 24,* 391-398.

Hsieh, L., Gandour, J., Wong, D., & Hutchins, G. D. (2001). Functional heterogeneity of inferior frontal gyrus is shaped by linguistic experience. *Brain and Language*, *76*, 227–252.

Jones, S. J., Longe, O., & VazPato, M. (1998). Auditory evoked potentials to abrupt pitch and timbre change of complex tones: electrophysiological evidence of 'streaming'? *Electroencephalography and Clinical Neurophysiology*, *108* (2), 131-42.

Kaukoranta, E., Hari, R., & Lounasmaa, O. V. (1987). Responses of the human auditory cortex to vowel onset after fricative consonants. *Experimental Brain Research*, *69*, 19-23.

Kayser, J., Tenke, C. E., & Bruder, G. E. (1998). Dissociation of brain ERP topographies for tonal and phonetic oddball tasks. *Psychophysiology*, *35*, 576–590.

Krishnan, A., Xu, Y., Gandour, J. T., &Cariani, P. (2005) Encoding of pitch in the human brainstem is sensitive to language experience. *Cognitive Brain Research*, *25*, 161–168.

Krishnan, A., Gandour, J. T., & Bidelman, G. M. (2010). The effects of tone language experience on pitch processing in the brainstem. *Journal of Neurolinguistics*, *23* (1), 81–95.

Luo, H., Ni, J., Li, Z., Li, X., Zhang, D., Zeng, F., & Chen, L. (2006).Opposite patterns of hemisphere dominance for early auditory processing of lexical tones and consonants. *Proceedings of the National Academic Sciences*, *103* (51), 19558–19563.

Martin, B. A., & Boothroyd, A. (1999). Cortical, auditory, event-related potentials in response to periodic and aperiodic stimuli with the same spectral envelope, *Ear and Hearing*, *20*, 33–44.

Martin, B. A., & Boothroyd, A. (2000). Cortical, auditory, evoked potentials in response to changes of spectrum and amplitude. *Journal of the Acoustical Society of America*, *107*, 2155–2161.

Näätänen, R. & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, *24*, 375-425.

Näätänen, R. (1992). *Attention and Brain function*. Hills dale, New Jersey: Lawrence Erlbaum Associates.

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: a review. *Clinical Neurophysiology*, *118*, 2544-2590.

Ostroff, J. M., Martin, B. A., & Boothroyd, A. (1998).Cortical responses to acoustic change within a syllable. *Ear and Hearing*, *19*, 290–297.

Picton, T. W., Alain, C., Otten, L., Ritter, W., & Achim, A. (2000). Mismatch negativity: Different water in the same river. *Audiology and Neurootology*, *5*, 111–139.

Putter-Katz, H., Kishon-Rabin, L., Sachartov, E., Gadoth, N., Pratt, H. (1999*).ERPs during phonological discrimination in dyslectic children.* Presented in 16th International Evoked Response Audiometry Study Group Biennial Symposium, Tromsö.

Sittiprapaporn, W., Chindaduangratn, C., & Kotchabhakdi, N. (2004). Brain electric activity during the pre-attentive perception of speech sounds in tonal languages. *Speech Sound Perception*, *26* (4), 440-445.

Tremblay, K. L., Friesen, L. M., Martin, B. A., & Wright, R. (2003). Test-retest reliability of cortical evoked potentials using naturally produced speech sounds. *Ear & Hearing*, *24*, 225-32.

Tremblay, K. L., Billings, C. J., Friesen, L. M., & Souza, P. E. (2006). Neural Representation of Amplified Speech Sounds. *Ear & Hearing*, *27*, 93–103.

Tremblay, K. L., Kalstein, L., Billings, C. J., & Souza, P. E. (2006). Neural Representation of Consonant-Vowel Transitions in Adults Who Wear Hearing Aids. *Trends in Amplification, 10* (3), 155-162.

Wang, Y., Behne, D., Jongman, A., & Sereno, J. A. (2004). The role of linguistic experience in the hemispheric processing of lexical tone. *Applied Psycholinguistics*, *25*, 449-466.

Yathiraj, A., & Vijayalakshmi, C. S. (2005).*Phonemically balanced word list in Kannada.* A test developed at Department of Audiology, AIISH, Mysore.