ACOUSTIC CHANGE COMPLEX IN NATIVE SPEAKERS OF TONAL AND NON-TONAL LANGUAGES

Registration No: 09AUD033

A Dissertation Submitted in Part Fulfillment for the Degree of

Master of Science (Audiology)

University of Mysore

Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE – 570006

June 2011

Dedicated to
my Parents
&
my Guide

CERTIFICATE

This is to certify that this dissertation entitled **‘Acoustic Change Complex in native speakers of tonal and non-tonal languages’** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No. : 09AUD033. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that the dissertation entitled **‘Acoustic Change Complex in native speakers of tonal and non-tonal languages’** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other university for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **'Acoustic Change Complex in native speakers of tonal and non-tonal languages'** is the result of my own study under the guidance of Dr. Sandeep M., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other University for the award of any Diploma or Degree.

Mysore Registration No. **09AUD033**

June, 2011

Acknowledgements

I thank God, almighty for making me what I am today and for making me strong by each passing day.

I thank Sandeep sir for his patience and guidance, and for giving us time even though he would be totally occupied by work most of the times. I had just heard about multi-tasking, you made me evidence it. Really hats off to yr patience and ability to think about multiple projects at a time. Sir, thank you very much for supporting me and teaching me a lot of things regarding Audiology and Research.

I thank Dr. S.R. Savithri, Director, All India Institute of Speech and Hearing for allowing me to do this research.

Dear Amma & Appa…I am blessed to have got you as my parents. For all the love, care, support & encouragement you have showered me with since the beginning of my life, I am very grateful. Words can't express my gratitude towards you.

Dear brother Shashi, thank you for all your pranks which made me smile in the busy days of dissertation. My life without you would have been boring.

And my sincere thanks to Ganapathi sir, Hemanth sir, Sujeet sir, Vijay sir, Arun Raj sir, Antony sir & Jithin sir for making our data

collection end within the time limit by opening the department on weekends and after 5.30 pm.

I have to thank Priya ma'am and the whole family of Sandeep sir for the very good hospitality whenever we went for dissertation work. Thank you one and all.

I would like to thank Sharath sir and Megha ma'am for their timely help. Thanks a lot!

I thank all my teachers from the days of my primary schooling till my post graduation for all that they have taught me and for being good role models to me.

I would like to thank Vasanthalakshmi ma'am for her help in doing statistics.

I am extremely thankful to all my participants for having patience with me and bearing a four-channel electrode placement recording. I would not have got more co-operative participants.

My sincere thanks to all the library staff for answering my queries whenever I was in need and to 'Raju' for his cheerful "Hi, Suma" whenever I stepped into the library.

Dear Dhatri, Anoop, Nike & Srikar, thanks a lot for all that you people have given me. AIISH wouldn't have been so colorful without you.

And thank you for all the suggestions and inputs you gave all throughout my life in AIISH.

Dear Prajna, thank you for being a good companion during my postings, I will cherish the days spent with you. Anisha, I can never forget you and your panicky nature. You always make me smile.

I would like to extend my thanks to all my Classmates for all the memories they gave for me to treasure all my life.

I thank all my juniors for everything they have been to me.
In case I have forgotten to thank anyone in the hurry-burry of dissertation, please don’t mind. I thank everyone who has helped me complete this project.

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Chapter 1

INTRODUCTION

As the principal avenue of human communication and interaction, speech is the most important signal we hear (Gelfand, 2001). Hence, it becomes an essential function of the central auditory system to efficiently encode speech. An understanding of how the nervous system accomplishes this task would provide important insight into the basis of language perception and cognitive function.

There are two basic approaches that researchers have adopted for conducting electrophysiological experiments on speech perception and underlying physiology. One approach uses ‘simple’ acoustic stimuli such as tones and clicks, as a means to control for the complexity of the speech signal (Abrams & Kraus, 2008). While simple stimuli enable researchers to reduce the acoustics of speech to its most basic elements, the auditory system is nonlinear (Sachs & Young, 1979; Sachs, Voigt & Young, 1983; Rauschecker, 1997; Nagarajan, Cheung, Bedenbaugh, Beitel, Schreiner & Merzenich, 2002), and therefore, responses to simple stimuli generally do not accurately predict responses to actual speech sounds. A second approach uses speech and speech-like stimuli (Kraus & Nicol, 2005; Krishnan, Xu, Gandour & Cariani, 2005). There are many advantages to this approach. First, these stimuli are more ecologically valid than simple stimuli. Second, a complete description of how the auditory system responds to speech can only be obtained by using speech stimuli. Third, long-term exposure to speech sounds and the subsequent use of these speech sounds in linguistic contexts induces plastic changes in the auditory pathway that may alter neural representation of speech in a manner that cannot be predicted by simple stimuli (Abrams & Kraus, 2008).

Speech is nothing but expressing oneself in codes which form a language. There are certain languages which use tone as a code to signal meaning of words which are phonetically same. Such languages which exploit phonologically contrastive variations in pitch at the word or syllable level are called tone languages (Gandour, 1994; Yip, 2003). A lot of research has been focused on such languages trying to explore the effects of experience-dependent plasticity on auditory processing. Most of them have found that assessing speech perception through auditory evoked potentials such as the Frequency Following Responses and Mismatch Negativity using native stimuli, will give better responses than with the nonnative stimuli (Krishnan, Xu, Gandour & Cariani, 2005; Chandrasekaran, Krishnan & Gandour, 2007).

One more interesting aspect in people who speak tonal languages is the hemispheric specialization in processing of speech which is embedded with lexical tone. It is reported that language processing is lateralized to the left hemisphere, whereas pitch perception is mediated in the right hemisphere for right-handed individuals (Zatorre, Belin & Penhune, 2002). The lateralization of lexical tone, where pitch is used to distinguish word meaning, provides a unique case. On one hand, tones involve a modulation of pitch, generally found to be the domain of the right hemisphere; on the other hand, they are used to make linguistic contrasts, assumed to be a function of the left hemisphere (Ryalls & Reinvang, 1986).

Studies conducted in the past on the hemispheric specialization of lexical tone processing have been contradictory. Few authors report a leftward asymmetry for the lexical tone processing (Wang, Behne, Jongman & Sereno, 2004; Gandour, 1998; Gandour, Wong, Hsieh, Weinzapfel, Van Lancker & Hutchins, 2000; Hsieh, Gandour, Wong & Hutchins, 2001) while few others report a rightward specialization (Luo, Ni, Li, Li, Zhang, Zeng & Chen, 2006).

In recent years, there has been an increasing interest in the use of cortical potentials to assess speech perception. There is a need to explore a specific electrophysiological response which is reliable and less time consuming for clinical usage. Most of the previous research in this area has involved mismatch negativity (Chandrasekaran, Krishnan & Gandour, 2007; Chandrasekaran, Krishnan & Gandour, 2009; Sittiprapaporn, Chindaduangratn & Kotchabhakdi, 2004), which is a negative ongoing, cortical event-related potential that occurs in response to an occasional deviant stimulus train of repeated standard stimuli. There are however, potential limitations to the use of mismatch negativity as a clinical tool. The amplitude of MMN is low in relation to background EEG activity (Picton, 1995). In addition, there is a practical limit to the amount of response averaging that can be done to increase signal to noise ratio (Martin & Boothroyd, 1999).

However, there is another event-related potential that might serve the purpose, namely the N1-P2 complex. This N1-P2 complex is termed as – Acoustic Change Complex (ACC) by Martin and Boothroyd (1999). Acoustic Change Complex (ACC) is a negative–positive complex that is elicited by a change that occurs during an ongoing acoustic stimulus and is reported to be most robust at the vertex (Martin & Boothroyd, 1999).

There have been a considerable number of studies that indicate ACC as being a useful measure for the clinical assessment of speech perception capacity. First, the ACC shows good correlation with behavioral measures of frequency discrimination (~10 Hz) (Martin, 2007; Ostroff, 1999; Danilkina, Wohlberedt & Hoppe, 2009) and also intensity discrimination (~3 dB) (Martin & Boothroyd, 2000). Second, the test-retest reliability of ACC has proven to be high at the individual participant level in adults (Tremblay, Friesen, Martin & Wright, 2003). Third, it is demonstrated that the ACC can be elicited in individuals with sensorineural hearing loss with and without hearing aids and cochlear implants (Billings, Tremblay, Souza & Binns, 2007; Brown, Etler, He, O'Brien, Erenberg, Kim, Dhuldhoya & Abbas, 2008; Friesen & Tremblay, 2006; Jerger & Jerger, 1970; Martin, 2007; Martin, Tremblay & Stapells, 2007; Tremblay, Billings, Friesen & Souza, 2006).

1.1 Justification for the Study

Thus, it clear from the above review that ACC can be used as clinical tool to objectively evaluate the representation of the stimulus spectra at the cortex. However, till date 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. Such an investigation can throw light on the nature of ACC being endogenous or exogenous. 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. 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 tone languages. Hence, these findings show a possible modification of the neural elements at the cortical level involved in the processing of lexical tones by language experience. 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.

1.2 Objectives of the Study

The present study was designed with the following objectives:

1. To determine whether the spectral change being lexical or non-lexical, influences the characteristics of ACC.
2. To analyze the cortical asymmetry (if any) in the generation of ACC, in native speakers of tonal and non-tonal languages.

Chapter 2

REVIEW OF LITERATURE

Speech perception is defined as the process of decoding a message from the stream of sounds coming from the speaker (Borden & Harris, 1980). It is nothing but the process of assigning meaning to the otherwise meaningless speech input, based on the experience, memory and knowledge of a particular language. The process of perceiving speech begins at the level of the sound signal and the process of audition. After processing the initial auditory signal, speech sounds are further processed to extract acoustic cues and phonetic information. This speech information can then be used for higher-level language processes, such as word recognition.

The speech signal contains a number of acoustic cues that are used in speech perception. The cues differentiate speech sounds belonging to different phonetic categories. Formants serve as the major cues for perception of vowels, (mainly the first two formants) and also the acoustic cues for the consonants are to some degree overlaid upon the cues of the neighboring vowels (Liberman, Delattre, Cooper & Gerstman, 1954). The listener will perceive the consonant and the vowel according to their acoustic relationship to one another.

It is a unique function of the human central auditory system to perceive and understand speech. It is through evolution that the human auditory system acquired this capacity of speech perception due to the pressing need to communicate. This indicates how important communication is to human species. Studying speech perception renders us the benefit of inferring the underlying concepts of language encoding and perception.

A language, on the other hand is a system of signs or codes for encoding and decoding information. Human language is highly complex in that it is based on a set of rules relating symbols to their meanings, thereby forming an infinite number of possible innovative utterances from a finite number of elements. Languages across the world vary in the type of speech sounds they use. Some use only the segmental variations to convey meaning, whereas some others make use of the intonations to signal different meanings of the words with same segmental characteristics. Such languages which exploit phonologically contrastive variations in pitch at the word or syllable level are called tonal languages (Gandour, 1994; Yip, 2003).

Tonal languages are defined as languages having lexically significant, contrastive, but relative pitch on each syllable (Beach, 1924; Pike, 1948). The languages of South-eastern Asia (China & Siam) and, West and South Africa are considered largely tonal (Tuker, 1940). Roughly 60-70% of world’s languages are tonal insofar as they utilize pitch to contrast individual lexical items or words (Yip, 2002). While tonal contrasts are primarily recognized by differences in the height or contour of the fundamental frequency (F_o), they may also involve duration differences.

Some of the languages spoken in the north-eastern part of India are tonal in nature (Manipuri, Mizo & Naga languages), which belong to Kuki-Chin group of the Tibeto-Chinese subfamily. One among them is Manipuri. Manipuri has three simple tones (rising, falling and level), two complex tones (rising-falling, falling-rising) and one compound tone (rising-falling-rising) (Radhakrishnan, 2005). Thus in terms of tonal inventory, Manipuri has six lexical tones. Due to this unique feature of lexical tones, tonal languages provide a unique window for exploring experience-dependent effects on the processing of acoustic stimuli.

Since several decades, auditory electrophysiology has been a useful tool for viewing such speech processing in the central auditory system. There have been a large number of studies (Kraus & Nicol, 2005; Krishnan, Xu, Gandour & Cariani, 2005, Chandrasekaran, Krishnan & Gandour, 2007, among others) which have made use of auditory evoked potentials to study the processing of spectral and temporal cues of speech at different levels of auditory neural system, in normal as well as pathological population. In the interest of the present study, earlier literature on tonal languages can be broadly divided into two main categories:

1. Literature in brainstem potentials
2. Literature in cortical potentials

2.1 Literature in Brainstem Potentials

Most of the studies which aim to determine the effect of linguistic experience on speech processing at the rostral brainstem have used the Frequency Following Response (FFR) (Krishnan, Xu, Gandour & Cariani, 2005; Krishnan, Gandour & Bidelman, 2010, among others) because it serves as an excellent tool to compare the pitch tracking ability in tonal language and non-tonal language speakers. Krishnan, Xu, Gandour and Cariani (2005) recorded FFRs elicited by four Mandarin tones in Mandarin Chinese and English speaking adults. Results showed that the Chinese group exhibited stronger pitch representation and smoother pitch tracking than the English group. Consistent with the pitch data, FFR spectral data showed that the Chinese group exhibited stronger representation of the second harmonic relative to the English group across all four tones. Hence, they concluded that, there was a possibility of the language experience induced neural plasticity at the brainstem level which may be enhancing the linguistically relevant features of the speech input.

Krishnan, Xu, Gandour and Cariani (2005) threw light on the effects of tonal language exposure on the processing of native language. Subsequently, Krishnan, Gandour and Bidelman (2010) tried to find out the extent to which this experience-dependent effect is specific to a particular language. Results revealed that irrespective of language, the two tone language groups exhibited higher accuracy of pitch tracking (Chinese & Thai) compared to the non-tone language group (English) and also for classifying English, Chinese, and Thai participants into their respective groups, moderate rising pitch was the important variable. Conclusion was that experience-dependent betterment of pitch representation extended to other languages with similar phonological systems.

Krishnan, Gandour, Bidelman and Swaminathan (2009) showed that the experience-dependent effects are not restricted only to speech stimuli of their respective language but also to non-speech stimuli which resemble the lexical tones relevant to that individual. They studied the experience-dependent neural representation of pitch in the brainstem using FFR in Chinese and English participants in response to an iterated rippled noise homologue of Mandarin Tone 2 (T2) plus linear and inverted curvilinear variants. The Chinese group showed advantages in terms of accuracy of pitch tracking and strength of pitch representation over the English in response to T2 only. Specifically, strength of pitch representation was larger only in rapidly-varying portions of T2 for the Chinese group compared to corresponding sections of a linear ramp. They concluded that experience-dependent neural plasticity at subcortical levels of representation is highly sensitive to specific features of pitch patterns in one’s native language.

The above studies demonstrated the effects of long-term exposure to tonal languages. There are certain other studies which have shown that even short-term exposure to tonal languages influence speech processing. One such study is by Song, Skoe, Wong and Kraus (2008) who trained the native English-speaking adults to incorporate lexical pitch patterns in word identification and then examined changes in the FFR to the trained pitch patterns before and after training. After training, they found increased accuracy in pitch-tracking, including a decrease in the number of pitch-tracking errors and a refinement in the energy devoted to encoding pitch. Most interestingly, this change in pitch-tracking accuracy occurred only in the pitch contour which is least familiar to the English-speaking subjects. They concluded that these results not only demonstrated the contribution of the brainstem in language learning and its plasticity in adulthood, but also the specificity of this contribution.

2.2 Studies in Cortical Potentials

According to corticofugal modulation theory, the corticofugal system influences subcortical sensory processing (Suga, Xiao, Ma & Ji, 2002). It was learnt in the above review that there was enhancement of brainstem representation of selective features of sound, which was experience dependent. Hence, there has to be an influence of the tonal language experience at the cortical level as well.

So to check this, Chandrasekaran, Krishnan and Gandour (2007) conducted a cross-language study utilizing the mismatch negativity (MMN). Their aim was to explore the influence of language experience on the pre-attentive cortical processing of linguistically relevant pitch contours. Chinese and English subjects were presented with Mandarin Chinese tones while the MMN was elicited using a passive oddball paradigm. Two oddball conditions were constructed with a common deviant, a low falling rising contour tone (T3). One condition consisted of two tones that were acoustically similar to one another (T2/T3: T2, high rising contour = standard). The other condition consisted of two tones that were acoustically dissimilar to one another (T1/T3: T1, high level=standard). Results showed that the mean MMN amplitude of the Chinese group was larger than that of the English group for the T1/T3 condition. No group differences were found for the T2/T3 condition. The mean MMN amplitude was larger for the T1/T3 relative to the T2/T3 condition for the Chinese group only. Hence, they concluded that early cortical processing of pitch contours may be shaped by the relative saliency of acoustic dimensions underlying the pitch patterns of a particular language.

The same authors in the same year (Chandrasekaran, Krishnan & Gandour, 2007) aimed to explore the influence of language experience on the saliency of dimensions underlying cortical pitch processing. MMN responses to Mandarin tones were recorded in ten Chinese and ten English participants using a passive oddball paradigm. Stimuli consisted of three tones (T1: high level; T2: high rising; T3: low falling-rising) and there were three oddball conditions. In the T1/T2 and T1/T3 conditions, each tonal pair represented a contrast between a level and a contour tone; the T2/T3 condition, a contrast between two contour tones. Twenty dissimilarity matrices were created using the MMN mean amplitude measured from the Fz location for each condition per participant, and analyzed by an *'individual differences multidimensional scaling model'*. Results indicated that two pitch dimensions were revealed, interpretively labeled as 'height' and 'contour'. The latter was found to be more important for Chinese than English subjects. Using individual weights on the contour dimension, a discriminant function showed that 17 out of 20 participants were correctly classified into their respective language groups. Hence, they concluded that, pitch features are differentially weighted depending on a listener’s experience with lexical tones and their acoustic correlates within a particular tone space.

The above studies highlighted the effects of linguistic experience only on one domain, that is, language. Later, Chandrasekaran, Krishnan and Gandour (2009) went on to examine whether experience-dependent effects on pitch representation were domain specific. They measured MMN and discrimination judgments of English musicians, English nonmusicians, and native Chinese for pitch contours presented in a non-speech context using a passive oddball paradigm. They used replicas of Mandarin high level (T1) and high rising (T2) tones, and a linear rising ramp (T2L) as stimuli. First condition involved a between-category contrast (T1/T2), the second, a within-category contrast (T2L/T2). Musicians and Chinese showed larger MMN responses than nonmusicians in all conditions; Chinese larger than musicians. However, Chinese were less accurate than nonnatives in behavioral discrimination of T2L and T2. Hence, they concluded that experience-dependent effects to pitch contours were domain-general and not influenced by linguistic categories.

Yet again the same authors (Chandrasekaran, Krishnan & Gandour, 2009) tried to assess the extent to which acoustic and phonetic change-detection processes contribute to the mismatch negativity (MMN) to linguistic pitch contours. They recorded MMN in Mandarin and English speakers using two oddball conditions. In the first condition, the high-level tone of Mandarin (T1) was compared with a convex high-rising tone (inverted T2, T2i) that was reported to occur as a contextual variant of T1 in running speech. In the second condition (T2/T2i), the concave high-rising tone (T2) was analyzed in comparison with T2i. They reported that phonetically, T1/T2i represented a within-category contrast for native speakers, whereas T2/T2i represented a between-category contrast. The between-category pair (T2/T2i) was more similar acoustically than the within-category pair (T1/T2i). In a behavioral procedure, the same speakers also performed an auditory discrimination task to determine the perceptual distinctiveness of the two tonal pairs. Results revealed that the Chinese group showed larger MMN responses and earlier peak latencies for both conditions, relative to the English group, indicating experience-dependent enhancement in representing linguistically relevant pitch contours. Also, that the Chinese group was less accurate than the English in discriminating the within-category contrast (T1–T2i). They concluded that experience-dependent neural effects at early pre-attentive stages of processing may be driven primarily by acoustic features of pitch contours that occur in natural speech. Also, that at attentive stages of processing, perception is strongly influenced by tonal categories and their relations to one another.

It is evident from the review that most of the studies have focused on Mandarin Chinese language. There are very few studies on tonal languages spoken in north-eastern part of India. In one such study, Radhakrishnan (2005) analyzed production and perception of Manipuri tones by native and non-native speakers. Non-native speakers comprised of 20 adult normal subjects in each group, speaking Hindi, Kannada, Malayalam, Telugu and Tamil. Results indicated that native speakers’ tone discrimination was significantly better than non-native speakers and some tone contrasts were best discriminated and some were not discriminated by non-native speakers.

Thus, from all these studies, it is clear that the pitch discrimination ability in the speakers of tonal languages is better compared to speakers of non-tonal languages. This finding arouses curiosity about the role of the two hemispheres in processing the lexical pitch, because right-handed non-tonal language speakers seem to have language comprehension and production lateralized into the Broca's and Wernicke's areas of the left hemisphere and the discrimination of aspects of music, including pitch, which leads to the understanding of tone or prosody lateralized to the right temporal lobe (Liégeois-Chauvel, Peretz, Babaï, Laguitton & Chauvel, 1998). In such a case, does the brain still lateralize tone processing to the right, does it shift it to the left, or are the two hemispheres activated to the same extent in speakers of tonal languages?

Gandour (2000) identified two major theories of prosody interpretation in the brain. One major theory argues that the neural components for sound processing are task- or domain-dependent, in that tone discrimination for speech would be a separate mechanism from tone discrimination for music. The other theory argues that the neural components are cue-dependent; different aspects of the acoustic signal are processed by different mechanisms regardless of whether the signal is speech or music. The task-dependent theory would predict that if linguistic tones are discriminated in the left hemisphere, it is still possible that musical tones could be discriminated in the right hemisphere. The cue-dependent theory would predict that tones would be discriminated in the same place regardless of whether they were a part of language or music (Missig, 2006).

There are various methods to explore the hemispheric specialization in an individual which include:

- Handedness
- Dichotic speech tests
- Neuroimaging
- Lesion studies
- Wada test
- Auditory evoked potentials

Handedness is an attribute of humans defined by their unequal distribution of fine motor skill between the left and right hands. It was Paul Broca who suggested that a person's handedness was opposite from the specialized hemisphere for language processing. Knecht et al., (2000) reported that the relationship between handedness and language dominance is not an artefact of cerebral pathology but a natural phenomenon. But few reports have been contradictory to this finding where a small proportion of right-handed individuals’ language dominance was routed towards the right-hemisphere (McManus & Bryden, 1991). Thus, making use solely of handedness to decide about the hemispheric dominance for language processing makes up for an inefficient measure.

Many earlier studies of lateralization of linguistic processing focused around dichotic listening experiments. Jäncke and Shah (2002) studied the relationship between dichotic listening and temporal lobe processing using fMRI. Results showed that dichotic listening caused much more activation in the frontal and temporal lobes than either single ear presentation. Hence, they concluded that dichotic listening might be testing more than just normal temporal lobe processing.

Neuroimaging tests provide us with several advantages, some of them being the opportunity of getting the functional information about cortical processing, good spatial resolution and getting all this non-invasively. However, the experimental task used may not only activate the brain areas solely related to that task, including sensory, motor and attentional systems. Thus, it requires that the activation of such systems be controlled by a baseline task.

It is well established that most of the right-handed individuals have their left-hemisphere as their dominant hemisphere for language processing. But it is not known to what extent the right hemisphere also takes part in such processing. Lesion studies come handy to investigate such a question. Springer et al., (1999) investigated the language dominance and factors that influence language lateralization in right-handed, neurologically normal subjects and right-handed epilepsy patients using functional MRL. They reported that the majority of both groups showed left hemisphere dominance, although a continuum of activation asymmetry was evident, with nearly all subjects showing some degree of right hemisphere activation.

The Wada test is also known as the “intracarotid sodium amobarbital procedure” and is used to establish cerebral language and memory representation of each hemisphere. Milner, Branch and Rasmussen (1964) performed Wada test on 48 right-handed adults and reported that 90% showed left hemisphere dominance for language and 10% showed right hemisphere dominance for language processing.

The auditory evoked potentials form the most useful tool for an audiologist in exploring the hemispheric specialization of an individual. Some of their advantages are that is a non-invasive procedure, provides excellent temporal resolution and are relatively easy to perform. Research utilizing EEG data for determining the hemispheric dominance have reported high auditory evoked potential amplitude over the left hemisphere with linguistic stimuli when compared to the right hemisphere (Callaway & Harris, 1974).

Sittiprapaporn, Chindaduangratn and Kotchabhakdi. (2004) went on to investigate the hemispheric specialization in the perception of native and non-native speech sounds. Mismatch negativity was elicited using single syllable change of both native and non-native speech-sound contrasts in tonal languages. EEGs were recorded and low-resolution brain electromagnetic tomography (LORETA) was made use of to explore the neural electrical activity. Results revealed that the left hemisphere was predominant in the perception of native speech sounds, whereas the non-native speech sound was perceived predominantly by the right hemisphere. They concluded that the results may be explained by the specialization in processing the prosodic and emotional components of speech.

When one does a survey of studies related to hemispheric specialization in tonal language speakers, he can find studies which have been conducted on hemisphere damaged individuals also. The following study mentioned will come in that category. Moen and Sundet (1996) studied two groups of hemisphere damaged speakers of East Norwegian with ten control subjects. Patients were selected from a group of stroke patients who did not suffer from neglect, global aphasia, or apraxia of speech. One group contained four left-hemisphere-damaged patients, while the other group had four patients with right-hemisphere-damage. Participants were shown written Norwegian words which differed only by tone and their task was to point to the spoken word. The control and right-hemisphere-damaged groups both performed well, while only one patient from the left-hemisphere-damaged group was able to identify all target words correctly. The other three left-hemisphere-damaged patients were 92%, 83%, and 50% accurate. Conclusion was that the left-hemisphere-damaged patients were more impaired than the right-hemisphere-damaged patients, and that the linguistic tone processing takes place in the left hemisphere.

Klein, Zatorre, Milner and Zhao (2001) conducted a PET imaging study in which native Mandarin speakers were compared with native English speakers on their ability to discriminate between Mandarin words which differed only by tone. Results revealed that the Mandarin group performed statistically better than English speakers. And the results of PET imaging showed Mandarin speakers had higher activation in the left hemisphere and did not have more activation in their right temporal lobes over baseline. English speakers showed more activation in their right temporal lobes and right frontal lobes than baseline when performing the tone discrimination task.

An interesting study was carried out by Luo, et al., (2006) which contradicted the results of the above mentioned studies. MMN was recorded in native Mandarin Chinese speakers by frequently presenting a meaningful auditory word with a consonant-vowel structure and infrequently varying either its lexical tone or initial consonant using an odd-ball paradigm to create a contrast resulting in a change in word meaning. Authors witnessed that the lexical tone contrast evoked a stronger pre-attentive response in the right hemisphere than in the left hemisphere, whereas the consonant contrast produced an opposite pattern. Hence, they concluded that this opposite lateralization pattern suggested the dependence of hemisphere dominance mainly on acoustic cues before speech input was mapped into a semantic representation in the processing stream.

The studies reviewed till now focused on the hemispheric specialization of native lexical pitch processing. Gandour, et al., (2000) tried to find out whether the processing of non-native lexical tone processing follows the same route as the native lexical pitch. They considered three groups of participants which included Thai speakers, Chinese speakers and English speakers. They presented unprocessed tonal Thai words in a discrimination task. They also presented low-pass filtered words with the idea that the filtered words would lose the linguistic content and thus be processed by the components responsible for non-linguistic acoustic processing. Results showed that only the Thai speakers showed more cerebral blood flow in the linguistic task than the non-linguistic task, and activation was in the left hemisphere. The comparison of linguistic task to baseline showed cerebral blood flow in both the left and right temporal lobes in all participant groups.

A similar kind of study was carried out by Valaki, et al., (2004) using MEG. There were three groups of participants consisting of 30 Mandarin, 20 Spanish, and 42 English speakers, all being right-handed. The participants were given a spoken-word recognition task in their native languages. Results showed that 100% of their Spanish-speaking population, 80% of their English-speaking population, and only 14% of their Mandarin-speaking population were left hemisphere dominant. They concluded that even though the spoken-word recognition task does not specifically answer the question of hemispheric dominance for lexical decisions, their results point to a fundamental difference in the organization of the brain mechanisms for spoken-word recognition in Mandarin speakers.

Most of the studies aimed at exploring the hemispheric specialization using AEPs have made use of MMN, but as already mentioned in chapter 1 (p. 3) MMN has potential limitations on its usage. Hence came up another auditory evoked potential named the Acoustic Change Complex.

Acoustic Change Complex (ACC) is a cortical auditory evoked potential (P1-N1-P2) elicited by a change within an ongoing sound stimulus (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 subject group encompassed of seven healthy participants. The results indicated that the vowel onset after voiceless fricative consonants evoked a prominent response in the supratemporal auditory cortex. They concluded that although the observed response seemed to be specific to acoustic rather than phonetic characteristics of the stimuli, it might reflect feature detection essential for further speech processing.

Then Jones, Longe and Vaz Pato (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.

At the same time, Ostroff, Martin and Boothroyd (1998) set off to investigate 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 auditory cortical evoked potentials N1 and P2 using three naturally produced speech stimuli the syllable [sei], the sibilant [s], extracted from the syllable and the vowel [ei] extracted from the syllable. AEPs were measured from eight normal hearing adults. They made sure that the extracted sibilant and vowel preserved the same time relationships to the sampling window as they did in the complete syllable. Five electrode placements were used which included Fz, Cz, Pz, A1, and A2, referenced to the nose. Group mean waveforms showed clear responses to both the sibilant and the isolated vowel. 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 but response to [s] was weaker than that to [ei]. 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 whatever may be the mechanism, the auditory cortical evoked potential to complex, time-varying speech waveforms can reflect features of the underlying acoustic patterns. They pointed out that such potentials may have value in the evaluation of speech perception capacity in young hearing-impaired children.

Overcoming the de-merits of their previous study related to cortical auditory evoked potentials to acoustic change within a syllable, Martin and Boothroyd (1999) conducted a more controlled study wherein they tried to investigate whether the acoustic change complex is elicited by a change of periodicity in the middle of an ongoing stimulus, in the absence of changes of spectral envelope or rms intensity. They also aimed at comparing the N1-P2 acoustic change complex with the mismatch negativity elicited by the same stimuli in terms of amplitude and signal to noise ratio.

For this purpose they used a tonal complex and a band of noise having the same spectral envelope and rms intensity. The signals were chunked to produce two stimuli that changed in the middle (noise-tone, tone-noise) to elicit the acoustic change complex. They also used two control stimuli created by concatenating two copies of the noise and two copies of the tone (noise-only, tone-only). An onset-to-onset interstimulus interval of 3 sec was used for recording of the potentials. Mismatch negativity was elicited using an oddball paradigm including the tonal complex and noise band stimuli (deviant probability = 0.14) with a 600 msec onset-to-onset interstimulus interval. The stimuli were presented via headphones at 80 dB SPL to 10 adults with normal hearing while the participants watched a silent video during testing. The authors found clear N1-P2 complex to the onset of the noise-only and tone-only stimuli whereas, the noise-tone and tone-noise stimuli elicited an additional N1-P2 acoustic change complex in response to the change in periodicity occurring in the middle. However, the acoustic change complex for the tone-noise stimulus was larger than for the noise-tone stimulus. Also, clear mismatch negativity was elicited by both the noise band and tonal complex stimuli. On the other hand, there was no significant difference in amplitude across the two stimuli and they also noted that the average amplitude of ACC was 2.5 times larger than MMN. Hence the authors concluded that the acoustic change complex was a more sensitive index of peripheral discrimination capacity than the mismatch negativity. This supports the possible utility of the acoustic change complex as a clinical tool in the assessment of peripheral speech perception capacity.

Martin and Boothroyd (1999) proved that it was possible to elicit the acoustic change complex solely with the change in periodicity with all the other parameters kept constant. Further, they were interested to know whether it was possible to do so by a change in spectrum and/or amplitude alone. So they conducted a study in the year 2000 to investigate this query. They recorded cortical auditory evoked potentials in eight adults in response to changes of amplitude and/or spectral envelope at the temporal center of a three-formant synthetic vowel of 800 ms duration. Authors reported that they were able to record a clear ACC to amplitude increments of 2 dB or more and decrements of 3 dB or more in the absence of any spectral change in the stimulus. In the presence of a change of second formant frequency from perceived /u/ to perceived /i/, amplitude increments increased the magnitude of the ACC but amplitude decrements had little or no effect. The fact that the just detectable amplitude change is close to the psychoacoustic limits of the auditory system argues well for the clinical application of the ACC. The failure to find a condition under which ACC is diminished by a small change of amplitude indicates that the observed ACC to a change of spectral envelope reflects some aspect of cortical frequency encoding. Taken together, these findings support the potential value of the ACC as an objective index of auditory discrimination capacity.

When the acoustic change complex was proving to be a beneficial clinical tool, Tremblay, Friesen, Martin and Wright (2003) wanted to examine how reliably it could be recorded in individuals. With this aim, they obtained auditory cortical evoked potentials from seven normal-hearing young adults in response to four naturally produced speech tokens (/bi/, /pi/, /ʃi/ & /si/). They tested and retested the participants within an 8-day period. Authors found out that the auditory cortical evoked potentials elicited by naturally produced speech sounds were reliably recorded in individuals. Also, naturally produced speech tokens evoked distinct neural response patterns. 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.

Once the ACC was found to be a reliable tool, its application could be extended to select the appropriate amplification device for an individual with hearing impairment. This possibility was experimentally investigated by Tremblay, Billings, Friesen and Souza (2006). They aimed to determine if (1) ACC elicited by amplified speech sounds can be recorded reliably in individuals, (2) amplification alters neural response patterns, and (3) different amplified speech sounds evoke different neural patterns. By recording ACC for amplified speech sounds (/si/ & /ʃi/) from seven normal-hearing young adults. Subjects were tested twice within an 8-day period in both aided and unaided conditions. Results revealed that (1) ACC could be recorded reliably in individuals in both aided and unaided conditions. (2) Hearing aids which provide a mild high-frequency gain only slightly enhance peak amplitudes relative to unaided cortical recordings. (3) Different neural response patterns for /si/ and /ʃi/ would be detected even neurally if the consonant-vowel boundary was preserved by the hearing aid. Hence, they concluded that speech-evoked cortical potentials can be recorded reliably in individuals during hearing aid use. However, a better understanding of how amplification influences neural response patterns is still needed.

After finding that ACC can be reliably recorded by amplified speech sounds in normal hearing individuals, Tremblay, Kalstein, Billings and Souza (2006) tried to investigate whether it was possible to do the same in individuals with sensorineural hearing loss. For this purpose, seven adults (50-76 years) with mild to severe sensorineural hearing participated in the study. When presented with two identifiable consonant-vowel (CV) syllables (/ʃi/ & /si/) & the neural detection of CV transitions was different for each speech sound. In specific, the latency of the evoked neural response coincided in time with the vowel onset, similar to the latency patterns the authors previously reported in normal-hearing listeners.

The next step was to find out whether ACC could be reliably recorded in individuals who use cochlear implants. Friesen and Tremblay (2006) tried to determine: 1) whether the acoustic change complex (ACC) could be reliably recorded in cochlear implant listeners and, 2) whether different speech sounds evoke distinct ACC patterns. Eight adults wearing the Nucleus-24 cochlear implant (CI) were tested using naturally produced speech tokens /si/ and /ʃi/. Using a repeated-measures design, participants were tested and retested within a 3-wk period. Results showed that intra-class correlation coefficients for grand mean and individual-response waveforms recorded from the syllables /si/ and /ʃi/ ranged from 0.63 to 0.89 from test to retest. Also, ACC latencies signaling the onset of a vowel in /ʃi/ were significantly earlier than those evoked by /si/. The authors concluded that because of its good stability and the ease with which it can be recorded in individual CI listeners, the ACC can be evoked using complex signals when studying central auditory function in CI listeners.

Later, Dimitrijevic, Michalewski, Zeng, Pratt and Starr **(**2008) examined auditory cortical potentials in normal hearing subjects to spectral changes in continuous low and high frequency pure tones. They recorded cortical potentials to increments of frequency from continuous 250 Hz or 4000 Hz tones. The magnitude of change was random and varied from 0% to 50% above the base frequency. Authors reported that the potentials consisted of N100, P200 and a slow negative wave (SN). N100 amplitude, latency and dipole magnitude with frequency increments were significantly greater for low compared to high frequencies. Dipole amplitudes were greater in the right than left hemisphere for both base frequencies. The SN amplitude to frequency changes between 4 to 50% was not significantly related to the magnitude of spectral change. Thus, they concluded that modulation of N100 amplitude and latency elicited by spectral change was more pronounced with low compared to high frequencies.

Danilkina, Wohlberedt and Hoppe (2009) tried to find out the relation between the Acoustic Change Complex and behavioral frequency discrimination for subjects with normal hearing. Twenty normal-hearing adults participated in the study. LAEP were recorded from eight electrode sites namely, Fc, Cz, FC1, FC2, F3, F4, C3 and C4 position. The acoustic stimulus was of 3000 ms and was made up of two parts: the 1000 Hz tone was presented for the initial 1500 ms and then increased by an onset of 2, 4, 6, 8 or 10 Hz for another 1500 ms. A 3AFC paradigm was adopted to measure the psychophysical discrimination for each frequency transition. Results showed that the ACC occurrence was associated with consistent discrimination of frequency transition in the 3AFC. In addition, some ACC parameters correlated significantly with behavioral discrimination results. The amplitudes of P2 response increased significantly with increasing stimulus onset. It was also noticed that the discrimination score of subjects for transitions, which did not elicit an ACC, were lower (50-100%) than if an ACC was observed (88-100%). But the difference was not significant.

Thus, from the above review we saw that ACC can not only be reliably recorded in normal hearing individuals but also in subjects with sensorineural hearing loss with and without hearing aids and cochlear implants. To add to its advantages, its occurrence correlates well with the behavioral discrimination of intensity and frequency. 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. The present study was an attempt in this direction where influence of linguistic factors like semantics on ACC was studied.

Chapter 3

METHOD

In this study, standard group comparison research design was adopted to test the hypothesis that there is no difference between the Acoustic Change Complex (ACC) recorded from the tonal language speakers and the non-tonal language speakers. The following method was used to verify the objectives of the study.

3.1 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 18-28 years (*M* = 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 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 speech perception in noise (SPIN) test. All of them obtained a score of >60% in both the ears. A written consent was taken from all the participants prior to their inclusion.

3.2 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 /t̪uI/ 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 /t̪uI/ 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 3.1-3.3.

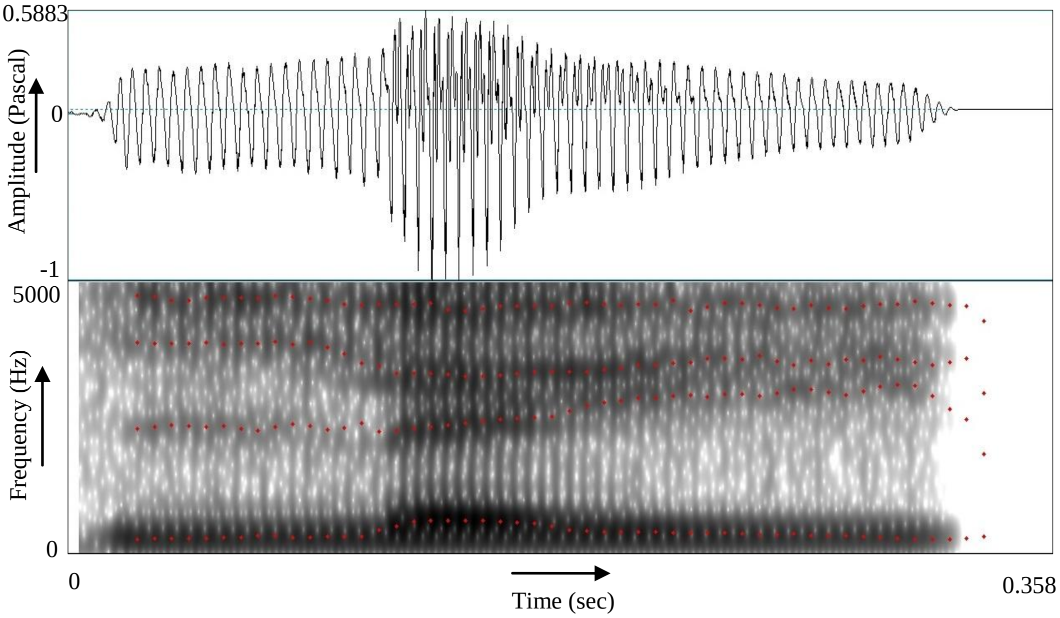

Figure 3.1. Time domain waveform and the spectrogram of /ḷaI-1/.

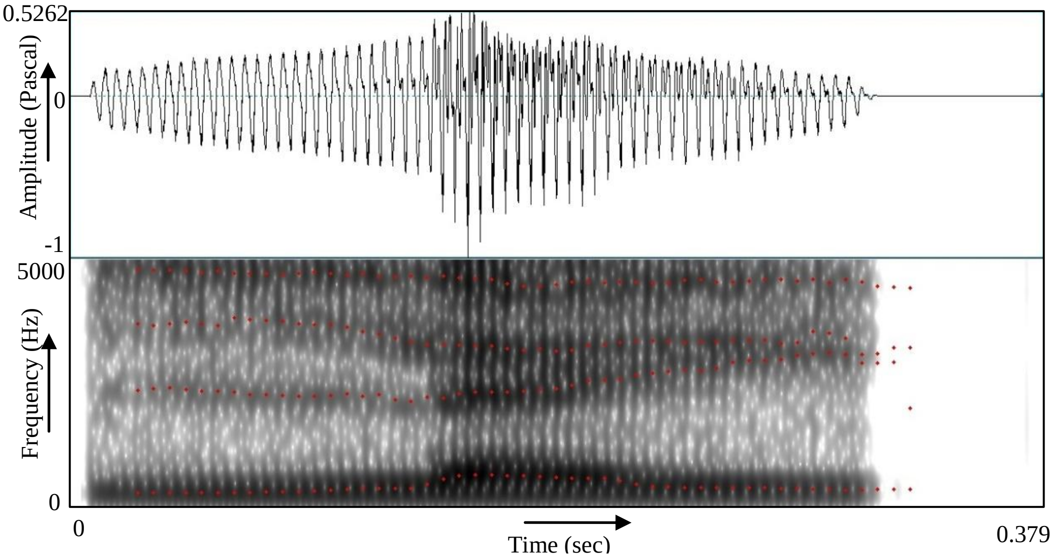

Figure 3.2. Time domain waveform and the spectrogram of /ḷaI-2/.

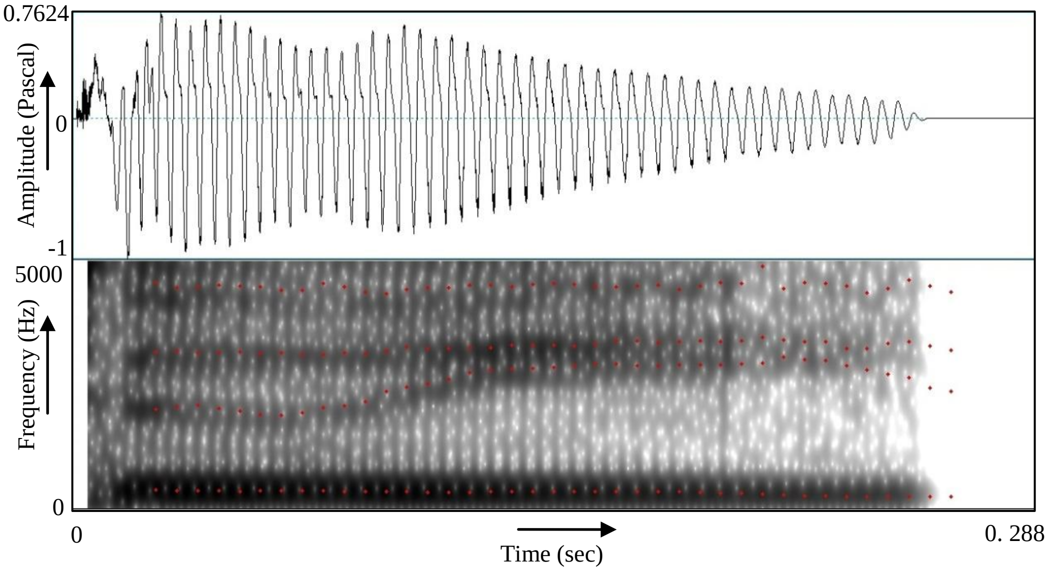

Figure 3.3. Time domain waveform and the spectrogram of /t̪uI/.

The spectral and temporal parameters of the three stimuli have been listed in Table 3.1.

Table 3.1: *Spectral and temporal parameters of the test stimuli*

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

Note: **NS-**No significant transition

3.3 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 Stadler Inc-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.

3.4 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 Pure-tone audiometry was carried out in a double room set up while the electrophysiological testing was done in a single room set up.

3.5 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 a 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, while the speech identification scores (SIS) were obtained at 40 dB SL 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.

3.6 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 3.2.

Table 3.2: *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	1-100Hz
Pre-stimulus time	100 ms
Sweeps	350

3.7 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 3.4. The responses were analyzed in terms of their latency, peak-to-peak amplitude and the morphology.

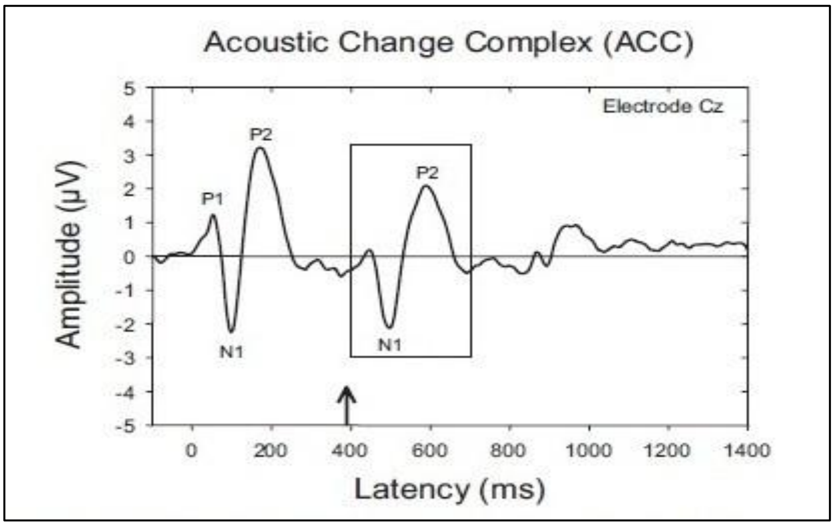

Figure 3.4. ACC recorded for the 800 ms stimulus /ui/ at Cz.
Note: Courtesy of Martin and Boothroyd, (2000).

3.8 Data Analysis

The results thus obtained were tabulated and statistically analyzed using Two-way repeated measure ANOVA, Bonferroni’s post hoc test, Independent t-test and Repeated measures ANOVA to determine whether it supports or rejects the null hypothesis.

Chapter 4

RESULTS

The primary aim of the present study was to analyze the influence of meaning associated with the stimuli on the Acoustic Change Complex (ACC). The secondary aim was to analyze the cortical asymmetry, if any, in the generation of ACC. To do this, 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). The following statistical tests were used in the present study:

- 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 either of the independent variables.
- 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 independent variables, repeated measures ANOVA followed by Bonferroni's post hoc was carried out

separately for 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 and peak to peak amplitude of N1’-P2’ obtained in both the groups for the three stimuli, across the three channels have been calculated and tabulated in Table 4.1. The trend observed in the mean data can be summarized as follows:

1. 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. It can be noted that the difference in the mean N1’ latency between the two groups is maximum for /ḷaI-1/, followed by /ḷaI-2/ and /t̪uI/, irrespective of the electrode site.
2. The mean latencies of P2’ for all the electrode sites and for all the stimuli are prolonged for Group I than those recorded from Group II. It can be noted that the difference in the mean P2’ latency between the two groups is maximum for /t̪uI/, followed by /ḷaI-1/ and /ḷaI-2/, irrespective of the electrode site.
3. The mean amplitude of N1’-P2’ for all the electrode sites and for all the three stimuli is higher for Group II than those recorded from Group I as can be seen in the Table 4.1. It can be noted that the difference in the mean N1’-P2’ amplitude between the two groups is 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 is slightly greater for /ḷaI-1/ than /t̪uI/, highest being for /ḷaI-2/.

Table 4.1: *Mean and Standard deviation (SD) of N1’ and P2’ latencies and the peak to peak amplitude of N1’-P2’ recorded for three Manipuri words, from three different electrode sites in the two groups of subjects*

Stimulus	Group	Wave	Latency (ms)						Amplitude (N1’-P2’) (µV)					
			Cz		C3		C4		Cz		C3		C4	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	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	3.42	1.02	2.67	0.88	2.73	1.09
		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	3.68	1.42	2.91	1.01	2.82	1.14
		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	3.63	1.07	2.76	1.09	2.90	0.87
		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	4.09	1.90	3.51	1.50	3.55	1.59
		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	4.18	1.47	2.98	1.19	3.13	1.09
		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	4.42	1.66	3.37	1.12	3.57	1.25
		P2’	283.67	12.95	283.76	13.26	283.29	12.57						

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 the following headings:

1. Results of latency of N1’ and P2’
2. Results of amplitude of ACC

4.1 Results of Latency of N1’ and P2’

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. Results are given in Table 4.2.

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’.

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 /t̪uI/ across all the channels in Group I. Along with the difference between /ḷaI-1/ and /t̪uI/, Group II also demonstrated a significant difference between the stimuli /ḷaI-1/ and /ḷaI-2/. The results are represented in Table 4.3.

Table 4.2: *Two-way repeated measure 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
	Channel X Group	0.726	2
	Stimulus X Channel	0.471	4 (124)
	Stimulus X Channel X Group	0.614	4
P2' latency	Stimuli	10.671*	2 (62)
	Channel	4.285*	2 (62)
	Stimulus X Group	1.065	2
	Channel X Group	3.405*	2
	Stimulus X Channel	1.118	4 (124)
	Stimulus X Channel X Group	0.896	4

*p<0.05

Table 4.3: *Results of Bonferroni's test for P2' latency*

	Group I			**Group I**		
Stimuli	**/ḷaI-1/**	**/ḷaI-2/**	**/t̪uI/**	**/ḷaI-1/**	**/ḷaI-2/**	**/t̪uI/**
/ḷaI-1/	-	NS	S	-	S	S
/ḷaI-2/	NS	-	NS	S	-	NS
/t̪uI/	S	NS	-	S	NS	-

Note: **S**-Significant (p<0.05); **NS**-not significant (p>0.05)

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. The results are represented in Table 4.4. Results revealed a statistically significant difference in N1’ latency between /ḷaI-1/ and /ḷaI-2/ and between /ḷaI-1/ and /t̪uI/. However, no such differences were noted between /ḷaI-2/ and /t̪uI/.

Table 4.4: *Results of Bonferroni’s test for N1’ latency*

Stimuli	**/ḷaI-1/**	**/ḷaI-2/**	**/t̪uI/**
/ḷaI-1/	-	S	S
/ḷaI-2/	S	-	NS
/t̪uI/	S	NS	-

Note: **S**-Significant ($p<0.05$); **NS**-not significant ($p>0.05$)

The waveforms of the ACC evoked by /ḷaI-1/ and /ḷaI-2/ recorded at Cz in Group II have been displayed in Figure 4.1 and those evoked by /ḷaI-1/ and /t̪uI/ recorded at Cz in Group II have been shown in Figure 4.2.

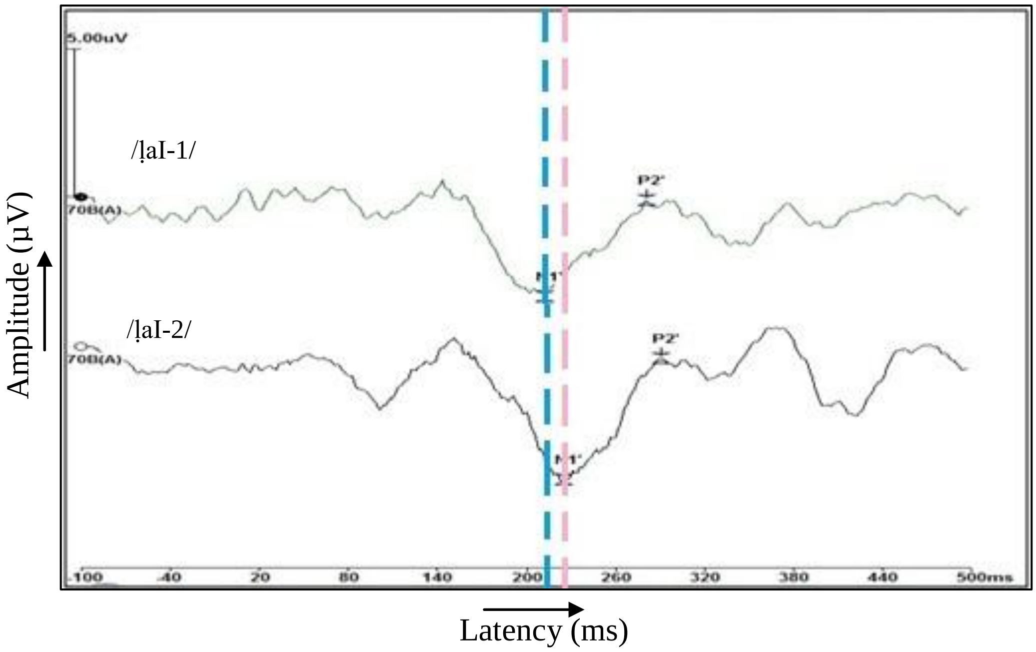

Figure 4.1. The Group II grand mean waveforms of the ACC evoked by /ḷaI-1/ and /ḷaI-2/ recorded at Cz.

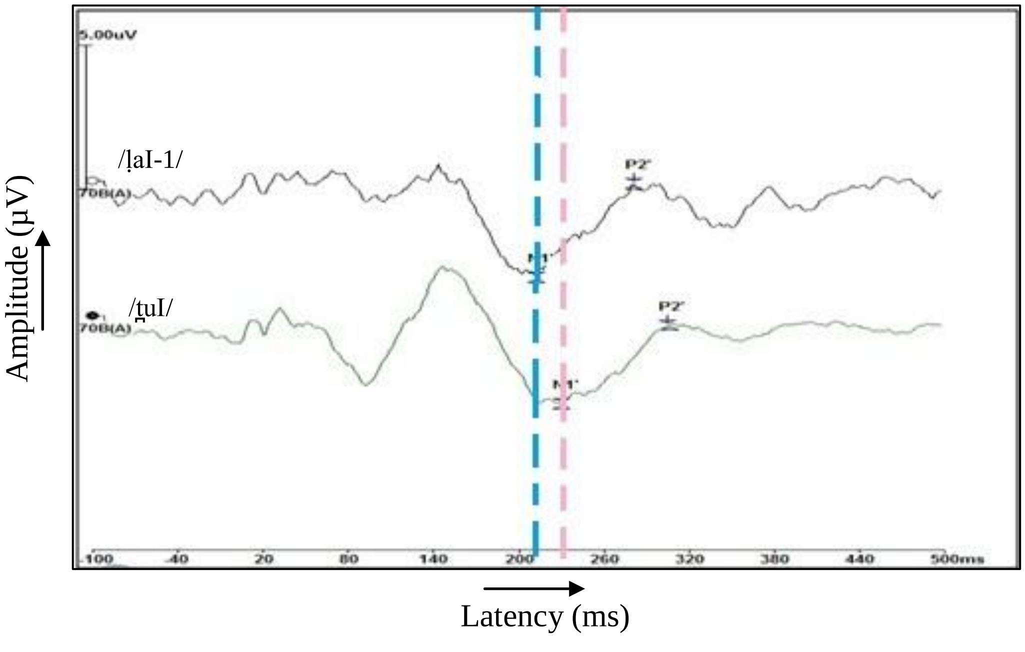

Figure 4.2. The Group II grand mean waveforms of the ACC evoked by /ḷaI-1/ and /ṯuI/ recorded at Cz.

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 4.5.

Table 4.5: *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

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/ in both groups at Cz, C3 and C4 have been displayed in Figure 4.3.

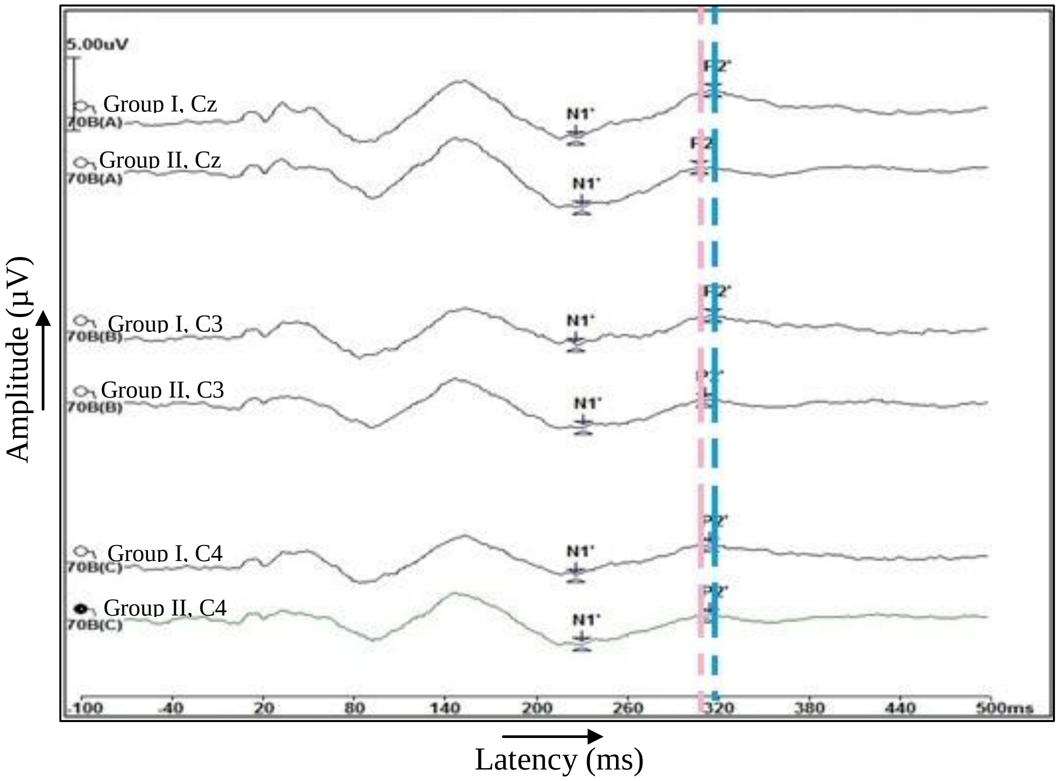

Figure 4.3. The Grand mean waveforms of the ACC evoked by /t̪uI/ in both groups at Cz, C3 and C4.

4.2 Results of Amplitude of ACC

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 4.6.

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.

Table 4.6: *Two-way repeated measure ANOVA for stimulus and channel with group as independent variable for N1'-P2' amplitude.*

Parameter	**Variable**	**F**	**df (error df)**
N1'-P2' amplitude	Stimuli	2.853	2 (62)
	Channel	100.388*	2 (62)
	Stimulus X Group	0.394	2
	Channel X Group	0.549	2
	Stimulus X channel	2.040	4 (124)
	Stimulus X Channel X Group	0. 486	4

$*p<0.05$

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, no such differences were noted between C3 and C4. The results have been outlined in Table 4.7. The Group II mean waveforms of ACC recorded at Cz and C3 and Cz and C4 sites have been displayed in Figure 4.4 and Figure 4.5 respectively.

Table 4.7: *Results for Bonferroni's test for N1'-P2' amplitude.*

Stimuli	**Cz**	**C3**	**C4**
Cz	-	S	S
C3	S	-	NS
C4	S	NS	-

Note: **S**-Significant ($p<0.05$), **NS**-Not Significant ($p>0.05$)

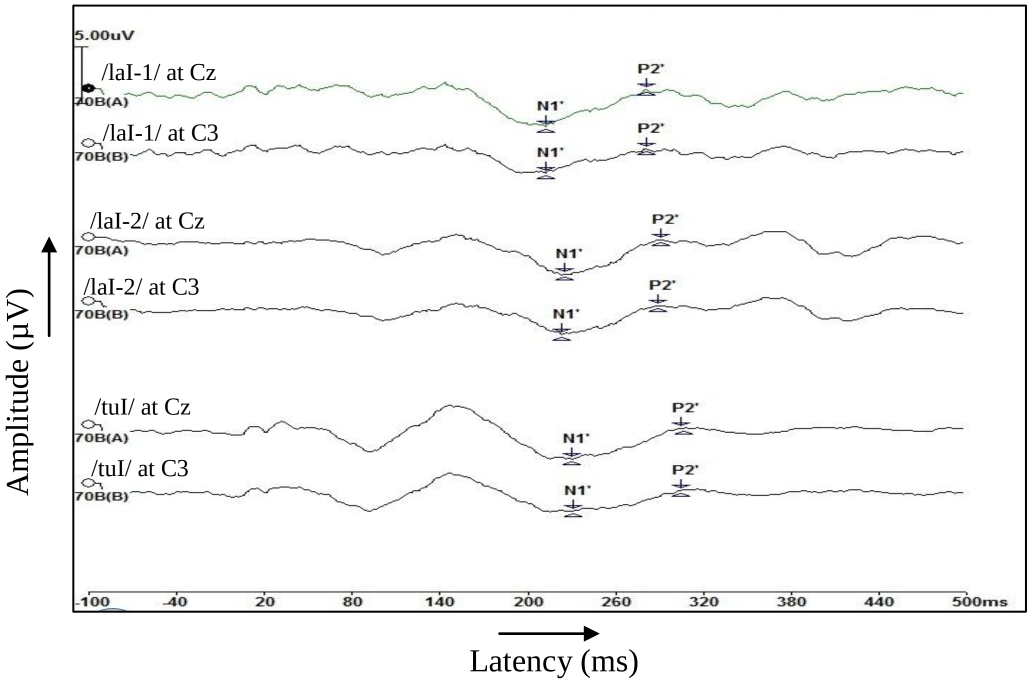

Figure 4.4. The Group II mean waveforms of the ACC recorded at Cz and C3 for the three stimuli.

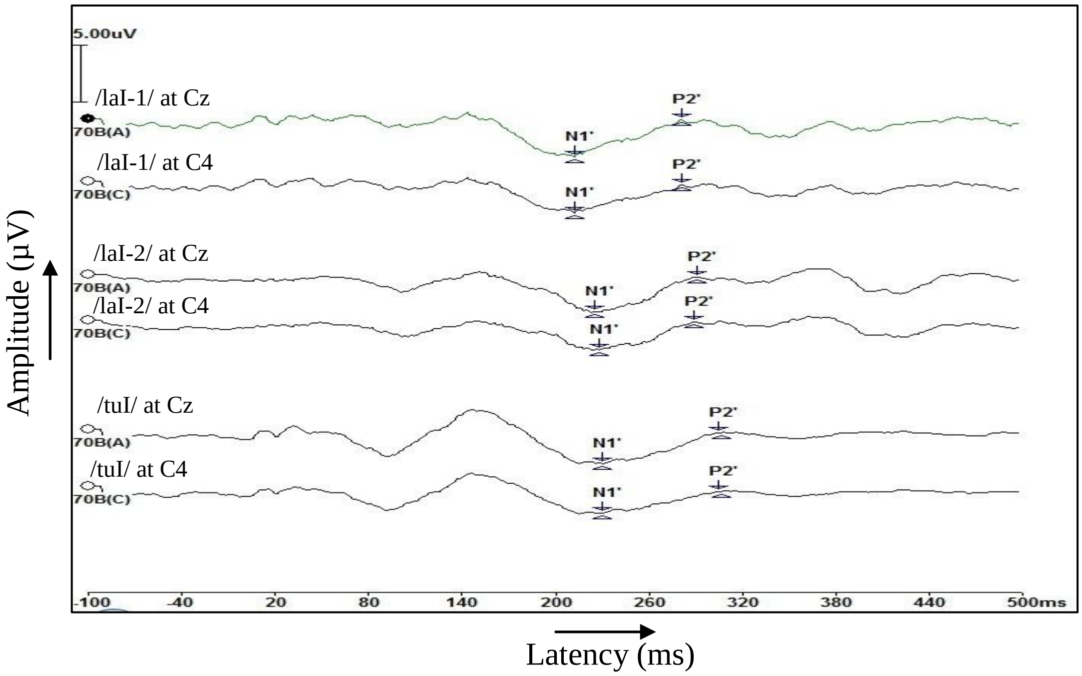

Figure 4.5. The Group II mean waveforms of the ACC recorded at Cz and C4 for the three stimuli.

Summary of Results

1. Comparison between the groups: The ACC recorded from the two groups was found to be statistically different in all the channels only in terms of the P2' latency for the stimulus /t̪uI/. It was noticed that the P2' latency for Group I was prolonged when compared to that of the second group.
2. Comparison between the stimuli: The statistical analyses comparing the stimuli overall indicated that ACC was significantly different when recorded using the stimuli /ḷaI-1/ and /ḷaI-2/ and /ḷaI-1/ and /t̪uI/. However, no significant differences were evidenced between /ḷaI-2/ and /t̪uI/.
3. Comparison between the channels: 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.

Chapter 5

DISCUSSION

The study aimed:

- To determine whether the spectral change being lexical or non-lexical, influences the characteristics of Acoustic Change Complex (ACC).
- To analyze the cortical asymmetry (if any) in the generation of ACC, in native speakers of tonal and non-tonal language speakers.

As the first step towards the goal, three monosyllabic words of Manipuri were chosen to elicit ACC in the native speakers of Manipuri and Kannada. Since the stimuli were of Manipuri language, the ACC elicited by Group I had the chance of being influenced by the lexical factors while, the same stimuli were not lexical for the Group II participants. So this experimental paradigm could assist in investigating the nature of ACC; lexical or non-lexical.

The present study was started with a null hypothesis that there is no difference between the Acoustic Change Complex (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/ also. 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, Kishon-Rabin, Gadoth & Pratt (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.

Moving towards the second objective of evaluating the cortical asymmetry (if any) in the generation of ACC, in native speakers of tonal and non-tonal language speakers, two of the stimuli selected namely, /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.

The results obtained are not in line with Sittiprapaporn, Chindaduangratn and Kotchabhakdi (2004) who analyzed cortical asymmetry in native speakers of tonal and non-tonal language using MMN. The discrepancy may be mainly due to the methodology utilized by the two studies. They made use of 21 electrode sites to check the difference in processing between the hemispheres, whereas the present study involved recording potentials from only three channels. So the difference that might have been present between the channels might not have been to the extent to reach statistical significance.

Also, the results may be thought to 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 to be done 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.

Chapter 6

SUMMARY AND CONCLUSIONS

The present study focused on the effect of experience-dependent plasticity on the ACC and to explore the hemispheric specialization of lexical pitch processing. Standard group comparison research design was adopted for the study with the assumptions that the native speakers of tonal language would exhibit the effects of long-term experience dependent plasticity and also that the hemispheric asymmetry would be highlighted in the processing of lexical pitch. The present study was designed with the following objectives:

1. To determine whether the spectral change being lexical or non-lexical, influences the characteristics of ACC.
2. To analyze the cortical asymmetry (if any) in the generation of ACC, in native speakers of tonal and non-tonal language speakers.

So to verify the reasons, two groups of participants were considered. Group I comprised of 16 native speakers of Manipuri and Group II had 17 native speakers of Kannada. Three natural monosyllabic words of Manipuri were chosen as stimuli to record the Acoustic Change Complex (ACC). Responses were measured from three channels, Cz, C3 and C4. The results thus obtained were tabulated and statistically analyzed using Two-way repeated measure ANOVA, Bonferroni’s post hoc test, Independent t-test and Repeated measures ANOVA.

The ACC recorded from the two groups was found to be statistically different in all the channels only in terms of the P2’ latency for the stimulus /t̪uI/. It was noticed that the P2’ latency for Group I was prolonged when compared to that of the second group. The differences between the channels were only evident for the amplitude of ACC. Responses at Cz were significantly of higher amplitude compared to C3 and C4, while no differences were found between the channels C3 and C4.

Since the differences between the groups were not significant across all the stimuli, it can be inferred that ACC is not endogenous. As the amplitude and latency of ACC were symmetric across 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.

Implications of the Study

The study threw light on the nature of ACC which has implications for future research and it further needs to be authenticated before being used for clinical purposes.

Future Directions

- A similar study can be carried out involving a large number of participants with multiple electrode placements.
- Possibly the stimuli (with lexical tones) used can be those which are routinely used by the participants to bring out the experience-dependent plasticity more evidently.
- Future studies can use techniques like fMRI along with AEPs to strongly interpret the scalp distribution of ACC.

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