Acoustic Change Complex: Neural Correlate of Speech in Noise Perception

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Abstract

This study investigated the potential of an electrophysiological measure, Acoustic Change Complex (ACC) in detecting the deficits in neural encoding of speech in the presence of noise and it also aimed to identify the neural factors (latencies and amplitudes) that determine good or poor speech perception in noise. Thirty typically developing children, between 12 to15 years participated in the study. They were divided into two groups based on behavioural speech in noise (SIN) scores as, group I (good scores) and group II (poor scores). Latency measures and peak to peak amplitude measures were obtained from ACC recordings for stimulus CV syllable /si/ in quiet and noise conditions of stimulus presentation. Results revealed significant differences between groups irrespective of the conditions and also between conditions irrespective of the groups. A significant correlation was observed between behavioural measure (SIN scores) and electrophysiological measures (latencies & amplitudes). These findings show the feasibility of using cortical responses in understanding individual's difficulty in perceiving speech in noisy background. Both latency and amplitude measures were found to depict speech perception capabilities.

Keywords: *Speech perception in noise, Acoustic change complex.*

Introduction

Speech perception involves interpretation of speech sounds ranging from simple phonemes to complex sentences (Boothroyd, 1997). Speech perception develops in childhood and is influenced by sensory factors, cognitive skills and linguistic abilities (Hnath-Chisolm, Laipply & Boothroyd, 1998). Amongst sensory factors, auditory modality has a major role to play. In other words, for understanding speech, maximum information is obtained through audition. Normal auditory processing of speech is particularly important in children. It provides a solid foundation for acquiring speech and language and in turn, academic skills such as reading and written language (Cunningham, Nicol, Zecker & Kraus, 2000). However, occurrence of auditory perceptual deficits which can impede normal speech perception is not uncommon in them. Such deficits can have adverse effects on language acquisition and in turn, literacy development. Elliott and Hammer (1988) suggested that in some children the root cause for the learning problems is auditory perceptual deficits specifically related to the processing of speech. Treiman, Broderick, Tincoff and Rodriguez (1998) have reported that children, who have auditory problems like difficulty identifying or discriminating phonemes, develop poor spelling and reading abilities.

Some of the auditory perceptual areas where children show deficits include - speech sound discrimination, temporal pattern recognition, auditory integration, localization, lateralization, speech in noise perception. Amongst these, most commonly reported auditory deficit in childhood is difficulty perceiving speech in the presence of noise (Cunningham et al., 2000). This specific perceptual difficulty also has been linked to learning problems. Chermak, Vonhof, and Bendel (1989) found that individuals with learning difficulties have poorer word identification in noise.

Speech consists of dynamic elements that require fine grained neural representation of temporal information. Noise disrupts the neural synchrony required for clear representation of those aspects of speech. This degraded representation of speech in the presence of noise at cortical and sub-cortical levels results in perceptual difficulties (Anderson, Skoe, Chandrasekaran & Kraus, 2010).

These reports from the literature, signifying the deleterious effects of background noise on processing speech, highlights the necessity of abundant research on identifying such problems using behavioral and electrophysiological measures to uncover and confirm those adverse effects. This would help in planning the management options at the earliest. There are a number of subjective tests for identifying poor speech in noise perception in children. Examples - Hearing in noise test (Nilsson, Soli & Sullivan, 1994), Speech Perception in Noise test (Bilger, Nuetzel, Rabinowitz & Rzeczkowski, 1984). But due to factors like cognitive dysfunctions, linguistic limitations, behavioral problems and others, conducting these behavioral tests in children to assess such perceptual deficits may become impractical most of the times. Thus, there is a clinical need to investigate on objective tests which have potential in identifying difficulties related to understanding speech in noise.

Auditory Evoked Potentials have been reported as being potential in reflecting difficulties related to encoding speech in noise. They provide a non-behavioral means

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of investigating the processing of speech (Ostroff, Martin & Boothroyd, 1998). Utility of sub cortical auditory evoked responses in identifying such deficits have been extensively researched. However, only a few investigations have been conducted on cortical event related potentials. As a result, very little is known about the relationship between central processes and the speech perception in noise. Among the cortical potentials, such studies using ACC are sparse. Thus, this study is an attempt to begin such an investigation to understand the neural encoding of speech in the presence of noise using ACC.

ACC is a P1-N1-P2 complex, elicited by acoustic changes in an ongoing stimulus. Both speech and non speech stimuli can be used to elicit this response. In non speech stimuli - intensity and/or frequency changes or modulations in sustained tones have been reported to elicit ACC (Spoor, Timmer & Odenthal, 1969; Jerger & Jerger, 1970). Also, Ross, Tremblay and Picton (2007) have reported occurrence of this response to inter-aural phase changes in non speech stimuli. In speech stimuli like simple syllables, the transition from consonant to vowel has been shown to elicit this response (Ostroff et al., 1998).

The literature on ACC using speech stimuli has suggested that it provides understanding about auditory system's ability to represent acoustic features present in the speech signal. In support of this, Martin and Boothroyd (2000) have reported that, ACC response can be recorded to the formant frequency changes within a vowel. Further, Martin (2007) reported that this cortical response has good agreement with behavioral frequency discrimination thresholds ($\approx$10Hz). However, whether the objective measures of ACC response can also represent degraded perception of speech stimuli in challenging listening situations like speech in the presence of noise and whether that representation has agreement with behavioral measures has not been investigated.

Method

Participants

Thirty school going children between 12 to 15 years were included. They were divided into 2 groups based on their Speech in Noise (SIN) scores. Group I consisted of 15 children (30 ears) with good speech in noise scores (SIN score $\geq$60%) while Group II included 15 children (30 ears) with poor speech in noise scores (SIN score $\leq$40%). In both the groups, there were 5 children each, in the age range 12 to 13 years, 13 to 14 years and 14 to 15 years. This criterion was to control the maturational effects. Group I consisted of 5 males and 10 females, while group II consisted of 7 males and 8 females. Gender match could not be obtained due to unavailability of the participants.

Children were recruited after obtaining written consent from their parents or guardians. Participants were native Kannada speakers with no history of any neurological, psychological, cognitive or otological problems and normal speech and language development. Air conduction thresholds (at the octave frequencies from 250 Hz to 8000 Hz) and bone conduction thresholds (at the octave frequencies from 250 Hz to 4000 Hz) were $\leq$15 dB HL. Also participants had bilateral normal middle ear function (Type 'A' tympanogram at 226 Hz probe tone and normal ipsilateral & contralateral reflexes at 500 Hz, 1000 Hz, 2000 Hz & 4000 Hz). Speech Recognition Thresholds (SRT) were $\pm$12dB to pure tone average and Speech identification scores in quiet were > 90% at 40 dB SL (ref. SRT). Further, TEOAEs (non-linear clicks of 260 sweeps at 80 dB pe SPL) were present (6 dB SNR & 90% reproducibility) and auditory brainstem response (wave V latency) for click were normal (Repetition rates = 11.1/s & 90.1/s, Intensity = 90 dB nHL). Children did not have any illness on the day of testing.

Test Environment

All testing were carried out in an electrically shielded and sound treated room where noise levels were maintained within permissible limits - ANSI S3.1 (1999).

Test Procedure

Preliminary evaluations: Detailed history regarding otological, neurological, psychological, and cognitive problems was taken along with the details of speech and language development. Once the possible deficits were ruled out in all these areas, pure tone audiometry, speech audiometry, immittance evaluation and TEOAE measurements were carried out. Further, only those children who passed the criteria in all the above evaluations were subjected to Speech in Noise testing.

Speech in Noise (SIN) testing: Phonemically balanced Kannada word lists developed by Vandana (1998) were used. Two lists out of four were considered. Words were presented through monitored live voice at 40 dB SL (ref. SRT) and 0 dB SNR (Speech noise). Twenty five bi-syllables in every list were presented for each trial and every word was given a score of 4%. Children had to repeat the words heard. Number of correctly identified words was noted down to find the SIN score. Children who fell into any of the two groups - Group I (SIN score $\geq$60%) or Group II (SIN score $\geq$40%) were considered for ABR and ACC recordings. This criterion was considered to have good distinction.

ABR and ACC recording: Participants were made to sit comfortably on a reclining chair. They were instructed to sit relaxed without much body and eye movements. They were allowed to watch DVD movies played without sound. Corrosion free silver chloride disc electrodes were used for recording. Absolute impedances were

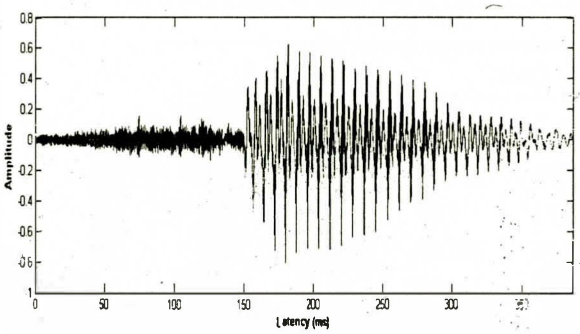

Figure 1: The acoustic waveform of CV syllable /si/ used to record ACC.

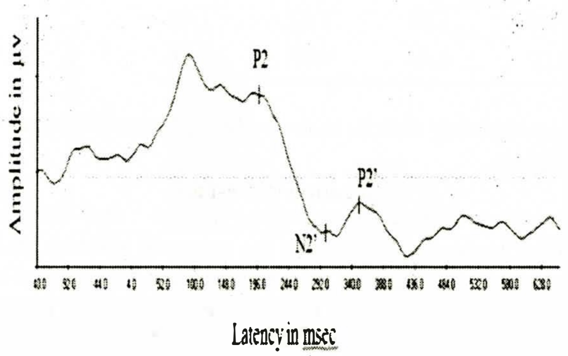

Figure 2: ACC response for syllable /si/ recorded from a typically developing child of age 13 years.

Table 1: Protocol used for ABR and ACC recording

	ABR	ACC
Transducer	ER-3A insert earphones	
Stimulus type	Click	CV Syllable-/si/
Stimulus duration	100 μs	386 ms
Stimulus intensity	90 dB nHL	80 dB SPL
Repetition rate	11.1/s &90.1/s	1.1/s
Sweeps	1500	250
Polarity	Rarefaction	Alternating
Electrode montage	Vertical	
Electrode sites	Inverting - Ipsi mastoid Non inverting - Cz (Vertex) Ground - Contra mastoid	
Amplification	1,00,000 times	50,000 times
Analysis time	12 ms	799 ms
Filters	100-3000 Hz	1-30 Hz
Notch filter	On	
Number of repetitions	2	

maintained within 5k Ω and relative impedances within 2 kΩ. Children who obtained normal wave V latency were only subjected to ACC recording. Protocol used for ABR and ACC recordings are shown in Table 1.

The consonant-vowel (CV) syllable /si/, spoken by an adult male native Kannada speaker was used as stimulus for ACC recording. The stimulus was recorded in a sound treated room using a dynamic microphone, placed at a distance of 10 cm from the lips of the speaker, at a sampling frequency of 44.1 kHz and 16 bit digitization. The recording and analysis of the stimulus was done using Adobe Audition software (version 1.5). Waveform of the syllable /si/, used in the study is shown in Figure 1. The duration of consonant portion /s/ was 149.6 ms, consonant vowel boundary was 2 ms, transition duration was 65.4 ms, Vowel duration (steady portion /i/) was 157 ms and total duration of /si/ was - 372 ms.

There were 2 conditions of stimuli presentation during ACC recording- /si/ syllable in quiet and /si/ syllable in noise (white noise presented ipsilaterally at 0 dB SNR). Totally, 4 recordings (2 in quiet & 2 in noise) were considered for analysis from each ear. A representative waveform of ACC recording with its latency and amplitude measures is shown in Figure 2.

Response Analysis

The replicable waves in each condition were averaged and analyzed for latencies and amplitudes by two experienced audiologists. Peaks were identified visually. Second positive peak of first LLR - P2, first negative peak, N1'and second positive peak, P2' of second LLR were marked. All latencies were calculated in milliseconds (ms). Also, peak to peak amplitude of P2-N1' and N1'-P2'complexes were calculated in microvolt (μV).

Results and Discussion

Overall data consisted of, Behavioral measure - SIN scores and Electrophysiological measures - Peak latency in ms (P2, N1' & P2'), and peak to peak amplitude in μV (P2-N1' & N1'-P2'). The data was tabulated and subjected to statistical analysis using the software, Statistical Package for the Social Sciences, SPSS (version 18).

Comparison of Measures between Ears

Paired t-tests were used to find differences between ears. Results indicated no significant differences ($p>0.05$). Hence, for further analysis measures of the two ears were combined.

Comparison of Stimulus Conditions (Quiet vs. Noise) and Groups (I vs. II)

Descriptive statistics of all latency and amplitude measures, for both groups in quiet and noise conditions are

Table 2: Mean and Standard Deviation of ACC Latencies and Amplitudes in Quiet and Noise

Parameters			Quiet		Noise	
			Group 1	Group 2	Group 1	Group 2
Latencies (ms)	P2	Mean	187.73	217.72	213.95	253.97
		SD	5.72	5.07	5.05	7.40
	N1'	Mean	262.38	283.09	286.96	322.74
		SD	4.80	4.92	6.55	7.27
	P2'	Mean	331.41	354.38	349.20	371.46
		SD	13.47	7.72	6.49	8.89
Amplitude (μV)	P2 -N1'	Mean	5.84	3.23	3.43	1.51
		SD	0.99	0.58	0.66	0.59
	N1'-P2'	Mean	2.46	1.58	2.02	1.42
		SD	0.67	0.43	0.58	0.36

shown in the Table 2. It can be observed from the tables that, when conditions were compared irrespective of the group, latency and amplitude measures were affected by noise i.e. latencies were delayed and peak to peak amplitudes were noticeably reduced. And when groups are compared, Group II (children with poor SIN scores) showed delay in latencies and reduction in amplitude compared to Group I (children with good SIN scores) in both the stimulus conditions.

To find whether these findings were statistically significant, Mixed ANOVA was performed. This provided information about main effects of conditions and groups and also the interactions between them. It was found that all main effects were significant in all the latencies and amplitudes ($p<0.001$). Also, interaction effects were significant except for the latency P2' and peak to peak amplitude N1'-P2'. Reasons for such findings for conditions and groups are discussed in the following sections.

Comparison of Groups (I vs. II) within Each Latency and Amplitude

As the results of mixed ANOVA showed significant interactions between groups and conditions, Multivariate Analysis of Variance (MANOVA) was performed for comparing the groups within each latency and amplitude measure.

Latency measures: Figures 3 and 4 show means and standard deviations for latencies between groups in quiet and noise conditions respectively.

Results revealed that there is a significant difference between two groups in all the three latencies for both the stimulus conditions. Such results were obtained for brainstem responses in study by Anderson and Kraus (2010). They reported that noise induces latency delays in children with poor speech in noise perception. They attributed the reason for such findings to temporal processing deficits in the auditory brainstem of such children.

However, precise neuro-anatomical and neurophysiological differences in the cortex of children with perceptual difficulties in noise are not explored still. Such differences might possibly disrupt the neural synchrony in those children which might be further degraded by adverse external conditions like noise leading to timing delays in cortical responses.

Amplitude measures: Figures 5 and 6 show means and standard deviations for amplitudes between groups in quiet and noise respectively.

Results showed a significant difference between two groups in both amplitudes for both the stimulus conditions. Anderson, Skoe, Chandrasekaran and Kraus (2010), studied brainstem correlates of speech in noise perception and found that children with poor perception in noise have reduced amplitude of neural measures. Explanation to such findings is majorly related to neuro-physiological differences of efferent system in good and poor listeners. Individuals with poor speech in noise scores have been speculated to have poor auditory efferent function (Kumar & Vanaja, 2004).

Studies on cortical potentials have failed to attribute the reason for decreased amplitude to any such central dysfunction observed in poor listeners. However, Anderson, Chandrasekaran, Yi and Kraus (2010), speculate that individuals with poor scores might be recruiting lesser neural resources due to lesser efficiency of the cortical pathway resulting in lesser amplitude.

Within Group Comparison of Latencies and Amplitudes between Conditions

Latency measure: Paired t test was used to study the latency differences between conditions within each group. Figures 7 and 8 show mean and standard de-

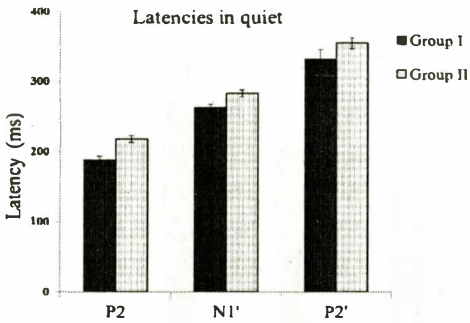

Figure 3: Means and Standard Deviations of latencies between Group I and II in Quiet.

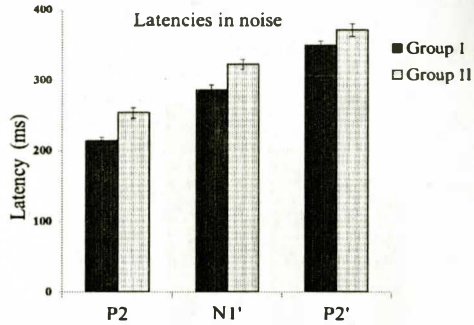

Figure 4: Means and Standard Deviations of latencies between Group I and II in Noise.

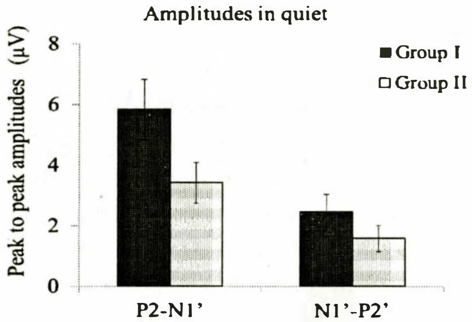

Figure 5: Means and Standard Deviations of amplitudes between Group I and II in Quiet.

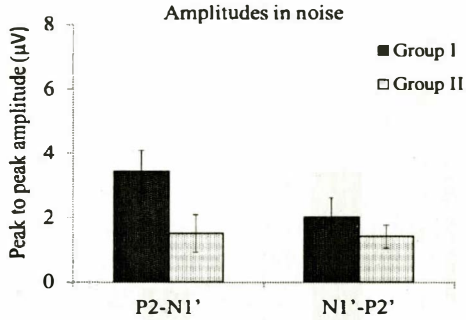

Figure 6: Means and Standard Deviations of amplitudes between Group I and II in Noise.

viations for latencies between stimulus conditions for groups I and II respectively.

Significant differences were obtained for all the comparisons of latencies between quiet and noise conditions in both the groups. These findings on latencies are in agreement with reports of several studies on evoked potentials both at sub-cortical (Cunningham et al., 2001) and cortical levels (Warrier, Johnson, Nicol & Kraus, 2004; Billings, Tremblay, Steker & Tolin, 2009). All those studies have reported delayed latencies for stimulus presented in noisy background. Possible reason for such findings can be disrupted neural synchrony due to noise which in turn may be reflected as delayed timing response of electrophysiological measures.

Amplitude measures: Paired t tests were used to study the amplitude differences between conditions within each group. Figures 9 and 10 show mean and standard deviation of amplitudes between stimulus conditions for group I and II respectively.

Again, significant differences were obtained for all the comparisons of amplitude measures between quiet and noise conditions in both the groups. As per the results, in both the groups introduction of noise has shown adverse effects resulting in reduced amplitudes. Wong, Uppunda, Parish and Dhar (2008) conducted a functional imaging study, where the stimuli were presented along with noise. Results revealed that cortical activation was less when stimuli were accompanied with noise and activation became lesser as the level of noise was increased. Such finding may support the speculation that amount of neural activation at the cortex is suppressed by noise which might result in reduced amplitudes of electrophysiological measures.

Other studies on cortical potentials reporting similar results are by Russo, Zeckler, Trommer, Chen and Kraus (2009) and Anderson et al. (2010). According to these researchers reduction in the amplitudes indicate poor sensory representation of acoustic aspects of signal in the presence of noise.

Correlation between Electrophysiological and Behavioral Measures

Pearson's correlation analysis was used to analyze the correlations between behavioral measure (SIN scores) and electrophysiological measures (latencies & amplitudes) in two conditions.

Results revealed a significant negative correlation ($p<0.001$) between latencies and SIN scores indicat-

Table 3: Correlation coefficient values between SIN Scores and Latencies in Quiet and Noise

Quiet			Noise		
P2	N1'	P2'	P2	N1'	P2'
-0.94	-0.91	-0.72	-0.94	-0.90	-0.76

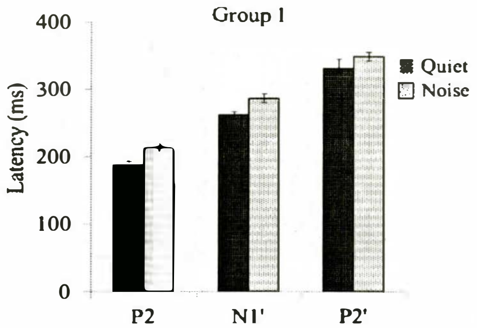

Figure 7: Means and Standard Deviations of Latencies between Conditions within Group I.

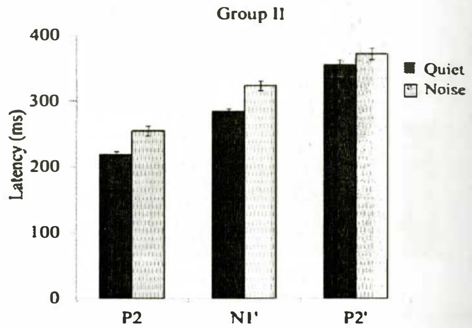

Figure 8: Means and Standard Deviations of Latencies between Conditions within Group II.

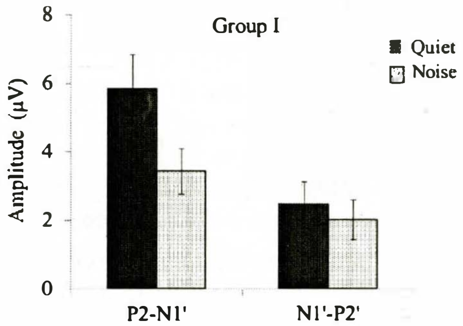

Figure 9: Means and Standard Deviations of amplitudes between conditions within Group I.

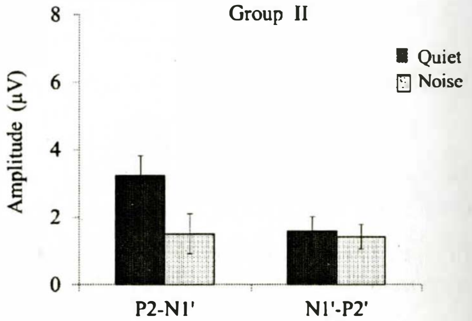

Figure 10: Means and Standard Deviations of amplitudes between conditions within Group II.

ing that as scores decrease the latencies increase and vice versa. Table 3 shows the correlation coefficient values between SIN scores and latencies. The above results show the robustness of relationship between cortical latency measures and speech in noise perception. These results are in support to the findings by Hornickel, Chandrasekaran, Zecker and Kraus (2011), who reported a link between behavioral SIN scores and subcortical neural measures. Results also showed a significant positive correlation ($p<0.001$) between amplitudes and SIN scores indicating that as scores decrease the amplitude also decrease and vice versa. Table 4 shows the correlation coefficient values between SIN scores and amplitudes. Anderson et al. (2010) correlated Hearing in Noise Test scores to N2 amplitude and found a significant correlation. Similarly, amplitude measures in this study also can be related to behavioral SIN scores. These results indicate that, electrophysiological measures act as neural signatures to behavioral speech perception in challenging environments.

Table 4: Correlation coefficient values between SIN Scores and Amplitudes in Quiet and Noise

Quiet		Noise	
P2-N1'	N1'-P2'	P2-N1'	N1'-P2'
0.84	0.61	0.82	0.61

Conclusions

The present study revealed that cortical potentials like ACC can also reflect the difficulties in speech in noise perception. Both latency and amplitude measures can be used to understand the perceptual and encoding difficulties posed by noisy background. These measures can potentially help us to identify children with difficulties in speech in noise perception. Robustness of the relationship between behavioral speech in noise and electrophysiological measures indicate that both at physical (as revealed by evoked potentials) and perceptual levels (as revealed by behavioral speech in noise test), effect of noise can be demonstrated. Also electrophysiological measures like latency and amplitude can act as neural correlates of speech in noise perception.

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