RELATIONSHIP BETWEEN SOME ASPECTS OF TEMPORAL PROCESSING AND SPEECH IN NOISE SCORES IN INDIVIDUALS WITH NORMAL HEARING

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This Dissertation is submitted as a part of fulfillment

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CERTIFICATE

This is to certify that this dissertation entitled **‘Relationship between Some Aspects of Temporal Processing and Speech in Noise Scores in Individuals with Normal Hearing’** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **16AUD034**. 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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This is to certify that this dissertation entitled **'Relationship between Some Aspects of Temporal Processing and Speech in Noise Scores in Individuals with Normal Hearing'** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **'Relationship between Some Aspects of Temporal Processing and Speech in Noise Scores in Individuals with Normal Hearing'** is the result of my own study under the guidance of Dr.Animesh Barman, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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Abstract

Communication in everyday situation involves listening in adverse conditions like in presence of noise or reverberation. To perceive speech in noise effectively, several auditory skills like temporal processing come into play to extract the key features in the input. The utilization of the temporal processing skill is highly variable in individuals with normal hearing sensitivity, and may lead to variations in the perception of speech in noise. The present study was taken up to explore these variations in temporal resolution ability, its neurophysiological mechanism at the level of brainstem and the use of these features and abilities for speech perception in noise. The study consisted of 60 ears of 30 native Kannada speaking adults in the age range of 18-25 years, who were assessed on their temporal resolution skills using behavioural measure of across channel gap detection test and electrophysiological measure of ABR at different intensities of 80, 60, 50 and 40 dB nHL for repetition rates of 11.1, 30.1, 70.1 and 90.1/sec. Speech perception in noise was assessed using PB words in the presence of speech shaped noise at three SNRs of 0, -3 and -5 dB SNR. The results of the study showed that there was a negative correlation between AC GDT and SPIN scores, with the magnitude of the correlation increasing with the decrease in the SNR, hence making AC GDT a good measure of predicting SPIN scores. There was also correlation seen between a slope of wave V across the repetition rates and at different intensities and SPIN scores, suggesting that temporal aspects of wave V is a better predictor of speech perception in noise scores. The variability in temporal resolution skills in individuals with normal hearing sensitivity was seen, and may be accounted to the differences in neural coding of temporal parameters.

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Chapter 1

Introduction

Speech is of utmost importance for everyday communication. It is characterised by spectral components such as formant frequencies, burst frequency, nasal murmur; temporal parameters such as voice onset time, transition duration, burst duration, vowel duration and intensity parameters such as burst amplitude, amplitude of frication and so on. These components are rapidly changing in terms of spectral and temporal characteristics. They add to the redundancy of speech and are important for perception of speech. Temporal envelope, which are the slow modulations associated with the syllabic and phonetic content in speech, are more important for speech perception rather spectral content (Drullman, 1995; Shannon, Zeng, Kamath, Wygonski & Ekelid, 1995). In the presence of noise, the temporal modulations of the target speech reduces as the noise fills in the peaks and troughs of the temporal waveform of the speech signal (Drullman, 1995), hence making perception in noise more difficult. Precise temporal processing is essential for listening well, especially in noisy environments (Dubno, Dirks & Morgan, 1984; Gor´don-Salant & Fitzgibbons, 1993; Snell & Frisina, 2000).

There are several tests which help in assessment of temporal resolution. The Gap Detection Test (GDT) is a straight forward measure of the temporal resolution, offering insight in the auditory perception (Philips, 1999) and also gives information on the speech perception (Philips & Smith, 2004; Papakonstantinou, Strelcyk & Dau ,2011; Helfer & Vargo, 2009; Summers, Makashay, Theodoroff & Leek, 2013). Gap detection threshold is the shortest interval of silence a listener can detect (Gelfand, 2009). Gap detection threshold can be obtained using two paradigms of gap detection threshold-within channel GDT and across channel GDT. It is thought that within channel GDT (WC GDT) is easier than across channel GDT (AC GDT), as WC GDT requires activation of neurons within in a single neural channel, whereas, AC GDT requires comparison of the timing of the neural activity with respect to the offset in one neuronal channel and onset in a completely different neuronal channel (Formby, Gerber, Sherlock & Magder, 1998; Grose, Hall, Buss & Hatch, 2001). It is also reported that across channel GDT has a better relationship with speech perception in noise than within channel GDT (Elangovan & Stuart, 2008; Walker, Brown, Scarff, Watson, Muir & Phillips, 2011). The AC GDT is a behavioural measure and is hence affected by extraneous variables attention, interest, procedural differences and understanding of the procedures.

Auditory Brainstem Response (ABR) is an onset response, occurring within the first 10-15 ms of the stimulus presentation. ABR is a highly sensitive tool to measure the integrity of the auditory brainstem, due to its replicability and temporal precision. The responses depend directly on the temporal synchronization of the activity of the neurons within an anatomical region (Jacobson, 1985). The morphology of the waves are dependent on the temporal course of the generation and the transmission of the neuronal activity and also the synchrony of the underlying activity related electrical potential.

Need for the study

Everyday communication involves perception of speech in adverse listening situations like in noise or in reverberation. It includes extraction of key features of auditory signal using several auditory processes. One such auditory process which aids in speech perception is the temporal resolution skill, which codes the changes in the auditory signal occurring over time. These processes can affect speech perception in noise, discrimination of phonemes and duration, perception of rhythm and prosody (Phillips, 2002; Chermak & Museik, 1997). Also, the utilization of such auditory abilities for speech perception is highly variable across individuals (Kidd, Watson & Gygi, 2007). Hence, temporal processing abilities required has to be assessed carefully even in individuals with normal hearing sensitivity. Thus, in the current study, AC GDT has been used to assess temporal resolution as it is correlated well with speech perception in noise (Philips & Smith, 2004; Papakonstantinou, Strelcyk & Dau ,2011; Helfer & Vargo, 2009; Summers, Makashay, Theodoroff & Leek, 2013).

Speech perception in noise is highly dependent on the temporal resolution skills (Papakonstantinou et al.,2011; Helfer & Vargo, 2009; Summers et al., 2013; Walker et al.,2011; Elangovan & Stuart, 2008; Fitzgibbons & Wightman, 1982; Moore, Glasberg, Donaldson, McPherson & Plack, 1989 and Gordon-Salant & Fitzgibbons, 1993). Most of the studies in the past have used behavioural measures of temporal resolution skills like low- rate frequency modulation detection (Ruggles, Bharadwaj & Shinn-Cunningham, 2011), amplitude modulation (Bharadwaj, Masud, Mehraei, Verhulst & Shinn-Cunningham, 2015), envelope interaural time difference (ITD) task (Bharadwaj et al., 2015). These behavioral tests can be easily affected by extraneous factors like attention, interest, procedural differences and understanding of the procedures. Thus, it is important to assess the temporal processing using an objective test which is less affected by the subject related factors. Hence, ABR has been used to assess temporal processing in the current study.

Secondly, speech perception degrades in the presence of noise, and this has been attributed to the reduction of the neural synchrony in noise (Hall, 1992; Burkard and Sims, 2002 and Russo, Nicol, Musacchia & Kraus, 2004). The underlying neurobiological mechanism for this neural activity is not explored. There are very few studies correlating speech perception in noise with electrophysiological measures at the level of brainstem.

Clinically, individuals are assessed based on pure tone audiometry and basic speech tests. But, several individuals with ‘normal hearing’ complain of difficulty in communication in adverse listening situations like in presence of noise, or in reverberating rooms. The mechanism underlying the processing of sounds in adverse listening conditions is not clearly understood and hence upon evaluation of such individuals, they may be labeled differently and not considered as clinical population. Also the site of lesion in the auditory pathway causing such disturbances in perception of speech is not defined.

Thus, the aim of the present study was to explore the relationship between speech perception in noise and temporal resolution skills using across channel gap detection test (behavioural measure) and temporal processing at the brainstem using Auditory Brainstem Response to clicks (electrophysiological measure).

Objectives of the study

The present study was taken up with the following objectives:

1. To observe the variation in SPIN scores in different SNRs in individuals with normal hearing sensitivity.
2. To explore the variation in AC GDT in individuals with normal hearing sensitivity.
3. To assess the variation in different parameters of ABR in individuals with normal hearing sensitivity.
4. To find out the relationship between Speech Perception in Noise (SPIN) scores at different signal to noise ratios and Across Channel Gap Detection Threshold (AC GDT).
5. To ascertain the relationship between SPIN scores at different signal to noise ratios and different temporal parameters of Auditory Brainstem Response (ABR) across intensities and repetition rates.

Chapter 2

Review of Literature

‘Normal hearing’ is usually defined by the threshold of audibility, using the pure tone audiometry. Many individuals with ‘normal hearing sensitivity’ complain of difficulty in communication in adverse listening situations like in the presence of background noise, or in reverberating rooms. When these individuals are evaluated, they may be labeled differently, and the underlying mechanism causing the difficulty in communication is not completely understood. The level at which the problem occurs, that is, peripheral, cochlear, neural or central is not defined. Also, understanding regarding the hierarchy of the processing of the sound is limited.

Everyday communication is beyond the detection of sound, and includes several auditory processes essential for extraction of key features of the auditory input. This utilization of these auditory abilities for speech perception is highly variable across individuals (Kidd, Watson & Gygi, 2007). Temporal processing is one such part of auditory processing, which gives information regarding the coding of the time related changes in the auditory input. Temporal processes constitutes temporal resolution, temporal integration, temporal sequencing and temporal masking (ASHA, 1996). These processes can affect speech perception in noise, discrimination of phonemes and duration, perception of rhythm and prosody (Phillips, 2002; Chermak & Museik, 1997). Precise temporal processing is essential for listening well, especially in noisy environments (Dubno, Dirks & Morgan ,1984; Gor´don-Salant & Fitzgibbons, 1993; Snell & Frisina, 2000).

Temporal processing can be assessed through several behavioural and electrophysiological measures. In this study, we made an attempt to assess temporal processing through behavioral test- gap detection test, neural coding through auditory brainstem response and aim to see their correlation with the scores of speech perception in noise testing. In this regards, information has been gathered from the available literature and has been put forth under several headings as given below.

2.1 Assessing temporal processing abilities using Gap Detection Test (GDT)

Gap detection test (GDT) assesses the temporal resolution of an individual, which is defined as the shortest time over which the ear can discriminate two signals (Gelfand & Gelfand, 2004). Temporal resolution is important for speech perception in noise (Dubno, Horwitz, & Ahlstrom, 2003; Oxenham & Bacon, 2003; Peters, Moore, & Baer, 1998). Gap detection testing, a psychophysical measurement, is considered a straightforward approach (Boets, Wouters, Wieringen & Ghesquière, 2006) and gives information about the auditory perception (Phillips, 1999) that may relate to speech perception (Phillips & Smith, 2004).

Gap detection threshold is the shortest interval of silence a listener can detect (Gelfand, 2009). GDT is known to have been affected by different stimulus parameters, like, stimulus bandwidth (Eddins, Hall & Grose, 1992; Snell, Ison & Frisina, 1994), stimulus duration (He, Horwitz, Dubo & Mills, 1999; Schneider & Hamstra, 1999), monotic, diotic, or dichotic presentation modes (Lister & Roberts, 2005; He et al., 1999, Gordon-Salant & Fitzgibbons, 1999), and the spectral similarity of the stimuli before and after the gap (Lister, Besing & Koehnke, 2002; Oxenham, 2000). Temporal acuity skills can be assessed across channels, that is, using narrow band noise (NBN AC) of different centre frequencies before and after the silence period. NBN stimuli gives frequency specific information, as compared to BBN. It is also thought that within channel GDT (GDT WC) is easier than across channel GDT (GDT AC), as WC GDT requires activation of neurons within in a single neural channel, whereas, AC GDT requires comparison of the timing of the neural activity with respect to the offset in one neuronal channel and onset in a completely different neuronal channel (Formby et al., 1998; Grose et al, 2001).

In a study done by Phillips, Taylor, Hall, Carr and Mossop (1997), GDT was measured using AC and WC paradigm. The study was done in four conditions. In the first condition, the stimulus for AC GDT was NBN centered at 2000 Hz as the leading marker, and the trailing marker was varied parametrically. It was seen that the gap detection thresholds got progressively worsened as the spectral distance increased. As the spectral distance of the lead and lag marker increased, the distance between the neural channels also increased, leading to difficult comparison of timing across the channels and hence, poorer GDT. They have also commented that AC GDT may correlate with the voice onset time (VOT) as the threshold is around 30 ms, corresponding to VOT.

Adaptive tests of temporal resolution (ATTR), a software, was used to evaluate GDT in thirty subjects with normal hearing sensitivity and revealed significant difference in GDT obtained using WC and AC (Lister et al., 2011). For the WC condition, the stimulus used was BBN and NBN of the same frequency (1000 and 2000 Hz). For the AC condition, NBN was used, centered around 1000 Hz and 2000 Hz, with different frequency NBN before and after the gap. It was seen that AC GDT was eight times larger than WC GDT. They explained that AC GDT is more difficult than WC GDT since the latter involves the activation of only one neural channel, and monitoring of activity in a single channel, whereas, the former is based on the comparison of relative timing of offset in one channel and onset in an entirely different neural channel.

Hess, Blumsack ,Ross and Brock (2012) evaluated WC and AC GDT across intensities using the ATTR software. The study was done on 50 subjects with normal hearing sensitivity, with the stimulus as NBN, centered at 1000 Hz and 2000 Hz. The results showed that, for both conditions, GDT decreased with increasing stimulus intensity, and large improvement was not seen for stimulus intensities above 20 dB SL. It was also observed that the variability was larger in the NBN-AC condition. This finding was accounted by reasons stated earlier (Lister et al., 2011).

Phillips and Smith (2004) studied on the correlation between the WC and AC GDT. The study was done on 95 subjects with normal hearing sensitivity, and the stimulus used was NBN centered at 1000 Hz and 4000 Hz, and for AC GDT, the leading marker was 4000 Hz and the trailing marker was 1000 Hz. Results showed that the gap detection thresholds were lower for the WC GDT than AC GDT. It was also seen that the thresholds were highly correlated between the two WC GDT (1000 Hz and 4000 Hz), and the thresholds were weakly correlated between the AC and WC GDT, that is, AC gap detection thresholds cannot be predicted by the WC gap detection thresholds and vice versa, suggesting different mechanism and pathways for AC and WC GDT. The mechanism underlying this phenomenon is similar to the explanation given by Lister et al. (2011).

Carmichael, Hall and Phillips (2008) studied the ear differences for temporal processing skills using AC and WC GDT, each under three contralateral masking conditions- no noise, continuous noise and interrupted noise, in subjects with normal hearing sensitivity. Results showed that there was a significant effect of noise on the gap detection thresholds. It was seen that the gap detection thresholds were longer for WC GDT for interrupted noise condition, whereas, the thresholds were shorter for AC GDT in the same masking condition, for the left ear. It was also observed that there were no ear differences for both the conditions, across all the masking conditions and the authors concluded that, if the left hemisphere has a temporal processing advantage, then, it is not seen in the gap detection testing.

2.2 Speech Perception in Noise (SPIN)

Speech perception in noise testing is affected by several parameters such as the type of noise used as the masker, the presentation level of the signal and the masker, hearing loss, age and so on. Studies which have used varying SNRs to see the effect of noise on SPIN scoresare discussed below.

In a study by Lecumberri and Cooke (2006), they used English CVC syllables to measure the perception in English and Spanish native speakers in the presence of four different types on maskers- eight talker babble, speech shaped noise, competing English and Spanish speech. The participants were 21 native English speaking adults and 61 native Spanish speaking adults in the age range of 18-24 years. The stimulus and the maskers were presented at 0 dB SNR to study the effects of energetic and informational masking at a fixed level of SNR. The participants were instructed to identify the consonant heard. They found that there is an effect of masker on the speech perception, with the best scores in the native competing speech and poorest scores for eight talker babble. For speech shaped noise, 70% consonant identification scores were obtained. This is due to the effect of only energetic masking in case of speech shaped noise, and a combination of energetic and informational masking for eight talker babble.

Manjula, Antony, Kumar, and Geetha (2015) developed a phonemically balanced word lists in Kannada for adults. In this project, they developed 21 PB word lists in Kannada. The long term average spectrum was extracted for all these words and was filtered with white noise to give speech shaped noise. This was mixed with the word lists to give -5 dB, -3 dB, 0 dB and +3 dB SNR. The word lists were presented at 40 dB SL in quiet and at the four different SNRs to 65 native speakers of Kannada with normal hearing sensitivity in the age range of 18 to 55 years. The participants were instructed to repeat the words heard. Statistical analysis was done for the scores obtained in quiet and at only -3 dB SNR. They observed 50% identification scores at -3 dB SNR.

Corbin, Bonino, Emily Buss and Leibold (2016) studied the development of susceptibility to two talker masker and speech shaped noise for an open set word recognition scores in children. They considered 56 children in the age range of 5-16 years and 16 English speaking adults with normal hearing sensitivity in the age range of 18-44 years for the same. The stimulus consisted of monosyllables in English which were presented at 65 dB SPL to the right ear. To vary the SNR from +6 dB to -6 dB SNR, the target stimulus was kept at a constant level, and the masker levels were varied. The individuals were instructed to repeat the words heard. The authors found that adults could obtain 50% correct scores at -4 dB SNR for speech shaped noise and at -2 dB SNR for two talker masker, and the differences are explained due to the combination of energetic and informational masking in two talker masker, and only effect of energetic masking in speech shaped noise.

2.2 Auditory Brainstem Response (ABR)

Auditory Brainstem Response (ABR) is a non invasive tool which represents the neural electrophysiological activity at the level of brainstem. The responses obtained are affected by several stimulus related factors like the intensity, repetition rate, polarity, type of stimulus and subject related factors like age, gender, head size and so on. The review of literature has found an effect of intensity and repetition rate on ABR. These are two stimulus parameters considered in the present study to assess the temporal processing using ABR.

Don, Allen and Starr (1977) conducted a study on six individuals with normal hearing sensitivity to check the effect of stimulation rate on click evoked ABR. The stimulus was presented at intensities of 30, 40, 50 and 60 dB SL for repetition rates of 10, 30, 50 and 100/sec. They measured the absolute latency of wave V as a function of intensity and repetition rate and observed a trend of increase in wave V latency with the increase in repetition rate and decrease in intensity; and the latency shift of wave V observed was 0.5 msec with the increase in the repetition rate from 10/sec to 100/sec at 40dB SL. The prolongation of wave V has been attributed to the metabolic changes occurring at the cells of neurons leading to adaptation and fatigue, leading to reduced neural synchrony.

Rowe (1978) studied the variability in auditory brainstem responses in 25 young adults in the age range of 17-33 years and 25 older adults in the age range of 51-74 years.

The click stimulus was delivered at the repetition rates of 10/sec and 30/sec at intensity of 60 dB nHL and 30/sec at 30 dB nHL. The responses were studied across different intensities and stimulation rates. It was seen that there was high intra and inter subject variability. It was noted that waves I, III and V were constant and replicable, whereas waves II, IV, VI and VII are variable, and are usually asymmetric or absent. It was observed that the peak latencies increased with increase in stimulation rate and decrease in intensity. This was justified due to dyssynchrony of neurons as the stimulation rate increases. The author has also concluded that wave amplitude alone is not a reliable measure of normality.

To study the ABR waveform variations in fifty adults with normal hearing sensitivity, Chiappa, Gladstone and Young (1979) varied stimulus parameters of clicks with intensity (60, 50, 40, 30 and 20 dB SL) and repetition rate (10, 18, 30 and 70/sec). They commented on various normal morphological patterns of wave III, wave IV-V complex, wave VI and VII. Their results also found the increase in absolute latencies of wave I, III and V with the increase in the repetition rate and decrease in intensity, reasons being adaptation of neurons and reduced neural synchrony. The authors have suggested the use of amplitude ratios as a better measure than absolute amplitude of waves I and V.

Stockard, Stockard, Westmoreland and Corfits (1979) elicited ABRs from 64 neurologically and audiometrically normal adults and 77 normal, full-term neonates. Te click evoked ABR was obtained for condensation and rarefaction polarity, at intensities of 30, 40, 50, 60 and 70 dB nHL at repetition rate of 10/sec. For three adults, ABR was recorded at the two polarities and at intensities of 70 and 50 dB nHL at the repetition rates of 10, 20, 30, 40, 50, 60, 70 and 80/sec. The results indicated that the peak latencies of wave I, III and V increased with the decrease in the stimulus intensity, with the effect more evident for wave I than wave V, and this has been explained due to the effects of adaptation of neurons with increase in repetition rate. Peak latencies increased with the increase in the stimulation rate and earlier latencies were obtained for peaks I, III and V for rarefaction than condensation polarity. They have also discussed the effect of the stimulus variations on the inter peak latencies. The authors suggest that wave I is more affected by intensity, due to the influence from the cochlea than wave V, which leads to variations in IPL with respect to wave I.

Fowler and Noffsinger (1983) evaluated the effect of stimulation rate and frequency of stimulus on ABR in 42 individuals with normal hearing sensitivity, cochlear hearing loss and VII nerve/ brainstem lesions. The stimulus, 2000 Hz and 4000 Hz tone pips, was presented at 75 dB nSL at the rate of 10 and 50/sec. They found that shorter latencies were observed for wave I and wave III for 4000 Hz than 2000 Hz, and an increase in absolute latency of wave I, III and V at 50/sec as compared to 10/sec repetition rate. They have attributed this delay in latency to the effect of adaptation of auditory neurons with the increase in repetition rate.

Suzuki and Takagi (1985) studied the effects of repetition rate of 8, 13.3, 23.8, 40 and 90.9/sec at 55 dB nHL on the slow (0-400 Hz) and fast (400-1500 Hz) components of click evoked ABR. The study was carried out on ten adults in the age range of 22-36 years with normal hearing sensitivity. The results exhibited greater effect of repetition rate on amplitude of fast than slow components of ABR. The latency of slow and fast components increased with the increase in the repetition rate. They have explained the increase in latency by the model of convergence and divergence by Pratt and Somher

(1976), which suggests that the lower order neurons activate a much larger number of higher order neurons as one moves up along the auditory pathway (divergence) and that each higher order neuron is activated by a large number of lower order neurons (convergence). Lack of cumulative neural activity at these two levels lead to reduced synchrony, and hence prolongation of wave V.

In a study by Jiang, Wu and Zhang (1991), they studied the effects of repetition rate on the amplitude of click evoked ABR in 80 healthy children and 21 adults. The repetition rates used were 10, 30, 50, 70 and 90 Hz at 70 dBnHL. Results showed that, as the repetition rate increased, the amplitude of wave I reduced comparatively more than the amplitude reduction of wave V, in both the age groups. The wave V/I ratio was analyzed, and it was seen that it increased with increasing repetition rate in all age groups, and the authors concluded that wave I amplitude was more affected than wave V amplitude with increasing repetition rate. They have attributed the change in morphology and intensity with increase in repetition rate to the reduction in synaptic synchronization and reduction in the neural activity due to lesser number of active neurons.

Gução, Romero, Lemes, Regaçone, Valenti and Frizzo (2015) aimed to characterize and compare the different polarity and repetition rates in ABR on 20 normal hearing female adults. The stimuli were presented in rarefaction and condensation polarity, at the repetition rates of 21.7, 27.7 and 47.7/sec at 80 dB nHL. The results exhibited shorter latencies for wave I in the three repetition rates and for wave V at 21.7/sec. Rarefaction polarity resulted in shorter latencies of wave I and wave V than condensation polarity. Similar results were obtained by Parthasarathy, Borgsmillert and Cohlan (1998), who studied the effect of phase and repetition rate of 11.1 and 55.5/sec in ten full term neonates and 10 adults with normal hearing sensitivity. These findings have been justified with similar reasons as the previous studies.

In the present study, we aim to measure the slope of wave V across the intensities at different repetition rates. To calculate the slope, Gopal & Kowalski (1999) gave a formula for the increase, r_i^{+} and decay of the wave, r_i^{-}. This formula was used to calculate the decay of wave V in the present study.

Increase of wave (positive slope), $\mathbf{r_i^{+} = v_{imax} - v_{I,r} \;/\; delta\ t_i^{-}}$

and

Decay of wave (negative slope) , $\mathbf{r_i^{-} = v_{imax} - v_{I,l} \;/\; delta\ t_i^{+}}$

where,

$v_{imax=}$ Max peak potential of the wave

$v_{I,r}$= Potential at the immediate succeeding right minima

$v_{I,l=}$ Potential at the immediate preceding left minima

delta t_i^{+}= Duration of the wave's ascent

delta t_i^{-}= Duration of the wave's descent

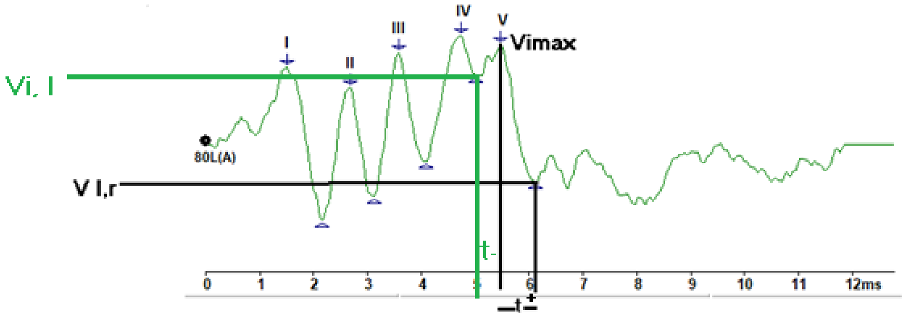

Figure 2.1 Representation of the formula for calculation of increase and decay of wave given by Gopal & Kowalski (1999).

2.3 Speech Perception in Noise and Temporal Resolution

Papakonstantinou, Strelcyk and Dau (2011) investigated the behavioural and objective measures of temporal processing and their relation with speech reception in noise, in seven hearing impaired listeners, with normal hearing sensitivity upto1 kHz, and steeply sloping hearing losses above 1 kHz, and five normal hearing individuals. The behavioural measures used were frequency discrimination, binaural masked detection and amplitude modulation detection. The objective measure for temporal processing used was ABR for clicks and broadband rising chirps. The speech perception in noise abilities was assessed by determining speech reception thresholds (SRTs) in speech shaped noise for Danish sentences. The results showed that the SRTs were not correlated with the hearing thresholds and the envelope based measure of temporal resolution, AM detection thresholds. SRTs were correlated with temporal fine structure coding measures, frequency discrimination and binaural masked detection thresholds. The chirp evoked ABR wave V thresholds correlated with the SRT and temporal fine structure measures. The authors have concluded by stating the importance of low frequency temporal processing, for the speech reception in noise, which can be affected even in individuals with normal hearing sensitivity according to the pure tone audiogram.

Helfer and Vargo (2009) studied the speech perception ability and temporal processing abilities in twelve younger women and twelve middle aged women with normal or near normal hearing thresholds, till 4000 Hz. The speech perception abilities of the individuals was assessed in the presence of steady state noise and competing speech, with and without perceived spatial separation of the target speech and masker. To assess the temporal processing abilities, gaps-in-noise (GIN) test was used. A subjective measure for their ability to understand speech in noise was done using a questionnaire. The results showed that the speech understanding ability in the presence of a spatially coincident spatial masker of the middle aged women was poorer than the young women. This was strongly correlated with the scores of the GIN test, and not to the pure tone thresholds. The speech perception abilities in presence of steady state masker was correlated to the high frequency hearing sensitivity pure tone threshold. The authors have suggested a strong relationship between temporal processing and speech perception abilities, especially in competing speech situations.

Gordon-Salant and Fitzgibbons (1993) investigated the speech perception abilities of young and older adults with normal hearing sensitivity with mild-to-moderate, sloping sensorineural hearing loss, using low predictability sentences from Revised-SPIN (R-SPIN), which was presented in three forms of temporal distortion- time compressed, reverberation and interruption. The temporal processing abilities were assessed using duration discrimination and gap detection tests. The results show that gap detection thresholds correlated to the scores of perception of reverberant speech.

Summers et al. (2013) investigated on frequency selectivity, peripheral compression and sensitivity to TFS information, in ten individuals with normal hearing sensitivity and eighteen individuals with HI. The tasks used were notched noise for frequency selectivity, temporal masking curve for peripheral compression and frequency modulation detection was used to check the sensitivity to TFS information. The testing was done at 500, 1000, 2000 and 4000 Hz, at different presentation levels. These individuals were also assessed for their sentence recognition abilities in steady state and modulated noise at different signal-to-noise ratios. The results showed that the speech recognition abilities in both the noise conditions correlated with the FM detection scores at 1000 and 2000 Hz, whereas, the frequency selectivity and compression measures was not clearly associated. The authors have concluded that reduced sensitivity to TFS cues affect the speech perception in noise, and also that the speech performance was not dependent on the audibility.

Walker et al. (2011) explored the temporal processing abilities and its relationship with reading performance in 38 children with LD in the age range of 11-14 years and 38 age matched typically developing children. The temporal processing abilities were assessed using within channel and across channel gap detection test, sequential and overlapping temporal order judgements tests. Phonological Awareness Quotient Subtest, the reading subtest of the Wide-Ranging Achievement Test-3, and short versions of the Olson Phonological and Olson Orthographic subtests were used to assess the language and reading skills of the participants. The results revealed significant correlation between temporal tasks of across channel gap detection test, overlapping order judgements test and reading performance.

Elangovan and Stuart (2008) checked for the relationship between voice onset time (VOT) of consonants and gap detection thresholds (GDT) in 18 native English speaking adults with normal hearing sensitivity. Gap detection threshold were obtained for within channel and across channel gap detection tests. To measure VOT, the stimulus used was a continuum from /ba/ to /pa/. Results exhibited differences in the GDT obtained from the two test paradigms, and the VOT phonetic boundary had a significant positive correlation with the across channel GDT and not for within channel GDT.

2.4 Speech Perception in Noise and Auditory Brainstem Response

Speech perception degrades in the presence of noise, and this has been attributed to the reduction of the neural synchrony in noise (Halls, 1992; Burkard and Sims, 2002 and Russo et al., 2004). Most of the studies have explored the correlation between SPIN and frequency following response for a speech stimulus in quiet and in presence of noise. Study by Bramhall, Ong, Ko and Parker (2015) correlating SPIN using QuickSIN with ABR elicited using 4000 Hz tone burst, at 80 dB nHL for a repetition rate of 13.3/sec, on young adults with PTA within 45 dB HL. They found that poor QuickSIN scores were correlated with the reduction of wave I amplitude of ABR, and there was association between wave I amplitude and speech perception in quiet.

Cunningham, Nicol, Zecker, Bradlow and Kraus (2001) conducted behavioural speech perception measures of just noticeable difference to the /da/-/ga/ continuum in quiet and in noise, click evoked ABR, speech evoked ABR to stimulus /da/ and cortical responses in typically developing children and children with learning problems. They observed a correlation between just noticeable differences in for conversational /da/-/ga/ continuum in noise, ABR wave V latency in noise and spectral content in the frequency range of 450-750 Hz. They reasoned the importance of neural synchrony to code for the temporal cues in speech, distinguishing steady state and dynamic information, and also to represent the stimulus effectively in noise. Study by King, Warrier, Hayes and Kraus (2002) conducted a similar study and also found a correlation between just noticeable differences for speech and FFR, but not with click evoked ABR. They have also attributed these findings to neural synchrony and its importance in perceiving speech in adverse conditions. These authors have emphasized on the importance of neural coding with respect to time at the level of brainstem for the perception of speech in noise.

Song, Skoe, Banai and Kraus (2011) carried out a similar study as above to find the relationship between speech in noise (SIN) using QuickSIN and neural encoding of F_o through speech evoked ABR for the stimulus /da/ in quiet and in noise (two talker and six talker babble). The participants were 17 native English speaking adults with normal hearing sensitivity in the age range of 17-30 years. The authors found that there is strong relationship between SIN and neural encoding of $F_{o;}$ poor SIN scores were correlated with degraded F_o coding in the presence of noise. They have suggested the differences in neural encoding at the sub cortex across individuals which may lead to differences in SIN scores. The authors have also suggested the importance of phase locking, especially of low frequency components (like F_o) which aid in speech perception in noise.

Lipson (2012) studied the relationship between speech perception in noise with R-spaced noise and speech evoked ABR in quiet and in pink noise at +10 dB SNR. The speech evoked ABR was elicited in mono and binaural conditions. The results showed with poor speech perception in noise, the sustained spectral portion of the F_o was affected. They have concluded that there is a link between poor SPIN and encoding of fundamental and low frequencies of speech, especially due to the phase locking capacities of the neurons at the level of brainstem.

Chapter 3

Methods

The current study was taken up to study the relationship between speech perception in noise and a few aspects of temporal processing in individuals with normal hearing sensitivity. To arrive at the aim of the study, the following methods were adopted.

Participants:

The study was done on 30 native Kannada speaking adults (60 ears) of age range of 18-25 years (Mean age: 20.77 years). The participants consisted of 10 males and 20 females. Both the ears of each participant were assessed, and all the tests were done in monoaural condition.

Subject selection criteria:

To rule out the presence of any peripheral auditory abnormality, a set of audiological tests were administered. All the 30 subjects (60 ears) were selected based on the following criteria:

- Otoscopy observation revealed normal external ear canal and tympanic membrane with cone of light present.
- Hearing sensitivity was within 15 dB HL in both ears, on pure tone audiometry (four frequency average of pure tone thresholds of 500, 1000, 2000 and 4000 Hz).
- 'A' type tympanogram with ipsilateral and contralateral reflexes were present at pure tone frequencies of 500, 1000, 2000 and 4000 Hz in both ears.
- Presence of transient-evoked otoacoustic emissions (TEOAE) in both ears.

- It was ascertained through a structured interview that none of the participants had a history of exposure to noise, music or intake of medicines for a long duration. Presence or history of neurological, otological or any associated problems at the time of assessment was ruled out.

Instrumentation:

The following instruments were used in the present study:

- A two channel diagnostic audiometer, GSI AudioStar Pro (Grasen-Stadler Incorporation, USA) was calibrated with the transducers TDH-39P headphones and Radio ear B-71 bone vibrator, according to ANSI S3.6 (2004). This was used for pure tone threshold estimation, speech audiometry and to evaluate speech perception in noise.

- A calibrated middle ear analyzer, GSI-Tympstar (Grasen-Stadler Incorporation, USA) was used for tympanometry and to assess the acoustic reflex thresholds.

- ILO V-6 Clinical OAE Software (Otodynamics Ltd., UK) was used to measure and analyze TEOAEs.

- Dell Inspiron 15 laptop loaded with Psycon V 2.18 experimental software was used to present the stimulus for Gap Detection Test. The stimulus was delivered through TDH-39P headphones.

- Intelligent Hearing Systems (IHS SmartEP windows, USB v4.0) with ER-3A insert earphones was used to record the auditory brainstem responses.

Testing environment:

The test was carried out in an air conditioned sound treated double room. The ambient noise level was within permissible limits (ANSI S-3, 1991).

Procedure:

Basic audiological evaluation:

- A detailed case history was obtained from all the participants to ensure they met the selection criteria of the present study. It was made sure that none of the participants were exposed to long durations of noise, music or subjected to prolonged medication for associated problems. They also had no history or presence of neurological and otological disorders.
- To determine the air conduction and bone conduction pure tone thresholds, modified Hughson and Westlake procedure (Carhart & Jerger, 1959) was used. It was assessed at octave frequencies, between 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction.
- As part of speech audiometry, the following measurements were considered. The speech recognition threshold (SRT) and speech identification scores (SIS) were measured and obtained using the Spondee word list developed by Vandana (1998) and PB word list by Yathiraj and Vijayalakshmi (2005) respectively. The PB words were presented at 40 dB above SRT. The uncomfortable loudness level (UCL) was obtained for running speech.
- Tympanometry was performed for the probe tone frequency of 226 Hz, with pressure varying from +200 daPa to -400 daPa. The ipsilateral and contralateral reflexes were obtained at pure tone frequencies of 500, 1000, 2000 and 4000 Hz.

- Transient evoked otoacoustic emissions were obtained for non linear click stimuli presented at around 75 dB SPL. It was considered to be present if the SNR was more than 6 dB SPL in at least three consecutive octave band frequencies, with reproducibility greater than 50% (Wagner, Heppelmann, Vonthein & Zenner, 2008).

The above mentioned tests were carried out to select the participants of the study. The tests administered to achieve the objectives of the study are given below.

Speech Perception in Noise (SPIN):

The SPIN scores were obtained using phonemically balanced words and noise developed by Manjula, Antony, Kumar and Geetha, 2015. There are 21 lists, with 25 PB words in each of the lists. For the present study, 7 word lists were used.

The test was preceded with familiarization of the procedure using 15 items presented at 0 dB SNR. The test consisted of presentation of the stimuli at the most comfortable level, monoaurally at three different SNRs: -5 dB, -3 dB and 0 dB. Each of the SNR conditions were randomized for every participant, and different word lists were used across SNRs for every individual. The stimuli were played on a personal computer and delivered through TDH-50P headphones of a calibrated audiometer, GSI AudioStar Pro. The participants were instructed to repeat the words perceived. Every correct response was assigned a score of ‘1’, and ‘0’ for every incorrect or no response. The maximum score of 25 could be achieved on the correct repetition of the 25 words in a list. The raw scores were recorded in the present study for the analysis.

Gap Detection Test (GDT):

The Gap Detection Threshold was estimated using an across channel paradigm. Signal processing and stimulus presentation was performed in Psycon v2.18 experimental software with a sampling rate of 44100 Hz, using AUX scripting (Kwon, 2012). The stimuli for the across channel paradigm was narrow band noise (NBN) with the center frequency of one being 1000 Hz and the other 2000 Hz, the former being the lead marker, and the latter the lag marker. The rise time of lead marker and fall time of lag marker was 30 msec. The duration of the lead marker was kept constant as 300 msec and that of the lag marker was varied from 250 msec onwards so as to eliminate duration as a cue for identifying the gap. The overall stimulus duration was kept constant within trials, by varying the duration of the lag marker, but was varied across trials. The standard or the reference stimulus had a constant gap duration, whereas the test stimulus had a variable gap duration. Ramping of one msec was used prior to and post the gap. The reference stimulus had a gap duration of one msec to reduce the spectral splatter. The initial gap duration was set to 50 msec and it was varied with respect to the subject’s response. The gap size increased with every incorrect response and decreased with two correct responses, with the step sizes being seven and two msec above and near the threshold respectively.

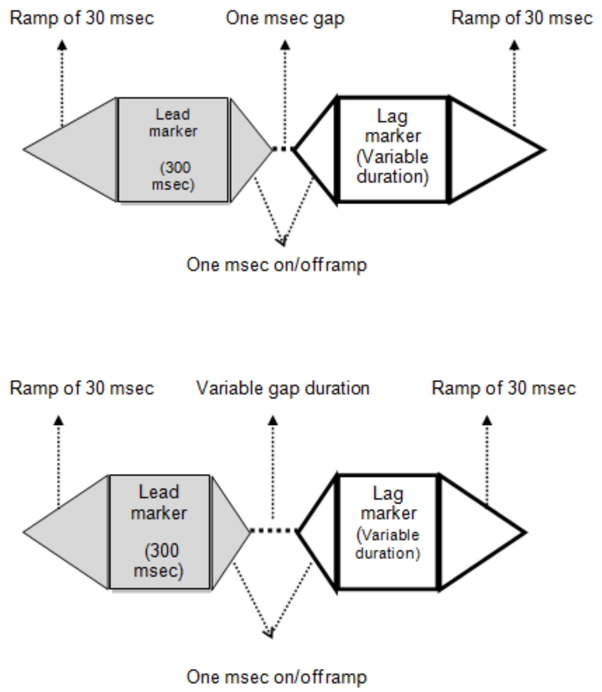

Figure 3.1 Schematic representation of the stimulus used for testing.

Prior to administering GDT, the thresholds for NBN centered at 1000 Hz and 2000 Hz was obtained using adaptive procedure in the Psycon v2.18 software. The most comfortable level (MCL) was obtained for the NBN of 1000 Hz and 2000 Hz, and the across channel GDT was measured at MCL. The GDT was assessed for both the ears, for every participant. The thresholds were determined by two down/one up adaptive procedure (2D1U), which results in the hit rate being 70.7% (Levitt, 1971).

The gap detection test was carried out using three interval three alternative forced choice method. The subject was exposed to the three forced choices with a time interval of 500 msec between them. The variable gap is introduced in a randomly chosen alternative and the task of the participant was to identify this stimulus correctly among the three. Following the response, the next trial began after a 1000 msec interval.

Figure 3.2 Response screen with the three alternatives.

The test was terminated after 8 reversals. The Gap Detection Threshold was calculated by obtaining the mean of the gap size of the last six reversals. The same procedure was administered thrice for each ear, and the across channel GDT value considered was the best GDT value among the last two trials. GDT values for each ear were noted for the analysis.

Auditory Brainstem Response (ABR):

A single channel click evoked ABR was carried out at 4 intensities- 80, 60, 50 and 40 dB nHL. At 80 and 60 dB nHL, the ABR was recorded at four different repetition rates of 11.1, 30.1, 70.1 and 90.1/sec. At intensities 50 and 40 dB nHL, it was recorded only at 30.1/sec repetition rate. Each condition had 1500 sweeps, which was replicated once. The recording was done using vertical montage with the negative electrode at the test ear mastoid, positive electrode at the vertex position and the ground electrode at the opposite ear mastoid. The ABR was measured for both the ears independently, in every participant. The protocol used to record ABR is given below:

Table 3.1

ABR Protocol Table

STIMULUS PARAMETER	SPECIFICATION	ACQUISITION PARAMETER	SPECIFICATION
Transducer	Insert earphone (ER-3A)	Electrode sites	Non inverting-Vertex Inverting-Mastoid of the test ear Ground-Mastoid of the opposite ear
Type of Stimulus	Click	Filter settings	100 - 3000 Hz Notch - None
Duration of stimulus	0.1 ms	Analysis time	15 ms
Stimulus Intensity	80, 60, 50, 40 dB nHL	Number of sweeps	1500
Repetition rate	11.1, 30.1, 70.1 and 90.1/ sec	Number of channels	One
Polarity	Rarefaction	Amplification	1,00,000

Waveform Analysis:

The waves were marked on the averaged waveform of the two responses in every condition. The waveforms were analyzed by two audiologists and the experimenter. The waves were marked where two out of the three agreed upon.

The following parameters were analyzed:

- Latency of wave I and wave V at intensities of 80 and 60 dB nHL for repetition rates of 11.1, 30.1, 70.1 and 90.1/sec; at intensities 50 and 40 dB nHL for repetition rate of 30.1/sec.
- Slope (latency shift per dB nHL) of Latency- Intensity function of wave V at the repetition rate of 30.1/sec. This was measured by finding the difference in latency shift in consecutive intensities divided by the difference of the two consecutive intensities considered.
- Duration of wave V, calculated as the time interval between the end of wave III and end of wave V, as wave IV was not clearly distinguishable from wave V in many participants. This was analysed at the intensities of 80 and 60 dB nHL for repetition rates of 11.1, 30.1, 70.1 and 90.1/sec; at intensities of 50 and 40 dB nHL at 30.1/sec.
- The slope of wave V was analyzed at 80 and 60 dB nHL at the four different repetition rates of 11.1, 30.1, 70.1 and 90.1/sec, using the formula described for decay of wave by Gopal & Kowalski (1999):

$$\textbf{Decay of wave V} = \mathbf{v_{imax} - v_{I,r} \,/\, t}$$

where,

v_{imax}= Max peak potential of the wave

$v_{I,r}$= Potential at the immediate succeeding right minima

t= Duration of the wave’s descent

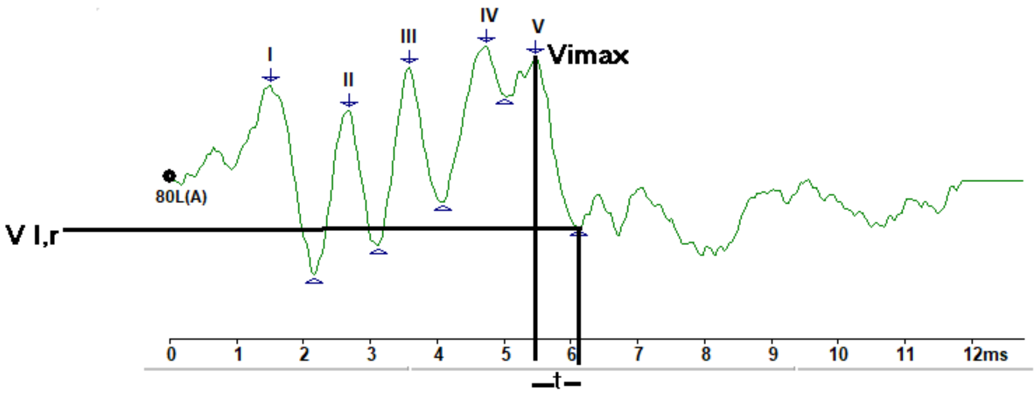

Figure 3.3: Representation of the calculation of slope of wave in the present study

- Inter peak latencies, the latency difference between wave III & wave I, wave III & wave V and wave V & wave I at intensity of 80 dB nHL for 11.1/sec repetition rate.

ANALYSIS

Gap detection threshold, SPIN scores and values of the different parameters of ABR were analysed for every individual to check for significant difference across the conditions in each of the three tests.

Correlational analysis was carried out to explore the relationship between SPIN scores and temporal resolution tests of GDT (behavioural measure) and temporal aspects of ABR (electrophysiological measure) to arrive at the objectives of the study.

Chapter 4

Results and Discussion

The current study was taken up to investigate the relationship between speech perception in noise and a few aspects of temporal processing, in individuals with normal hearing. In this study, the tests considered to evaluate temporal processing were across channel Gap detection test (AC GDT), a behavioural measure and Auditory Brainstem Response (ABR), an electrophysiological measure. The speech perception in noise was tested at three SNR conditions: 0 dB SNR, -3 dB SNR and -5 dB SNR. The data was collected from 60 ears of 30 individuals with normal hearing sensitivity, and was analysed using Statistical Package for Social Sciences (SPSS, v20). Descriptive analysis was done to obtain the mean, standard deviation, median and the minimum and maximum value. Inferential statistics were used to check for statistical significance of differences and correlations.

4.1 Test for normality

To check whether the data followed normal distribution, Shapiro Wilks test was performed. The results showed that many measures of data were not normally distributed, and hence, for further analysis, non parametric tests were used. Median values were considered as a representative of data.

4.2 Speech Perception in Noise

The SPIN scores obtained at 0 dB SNR, -3 dB SNR and -5 dB SNR were tabulated and descriptive analysis was carried out for the same. The mean, standard deviation, median, minimum and maximum values are given in Table 4.1.

Table 4.1

Mean, SD, median, minimum and maximum values for SPIN scores across SNRs

Test Statistics/ SNR condition	0 dB SNR	-3 dB SNR	-5 dB SNR
Mean	20.88	14.75	10.28
SD	1.11	1.63	1.45
Median	21	15	10
Minimum	19	12	8
Maximum	24	18	14

From Table 4.1, it can be observed that the mean SPIN scores and median scores decreased with the decrease in the SNR. Similar results were also obtained by Manjula et al. (2012), Corbin et al. (2016) and Helfer et al. (2008).

Speech consists of spectral, temporal and amplitude parameters. Previous studies by Drullman (1995) and Shannon et al. (1995) highlighted the importance of temporal envelope rather than spectral information to perceive speech in quiet. When the spectral information was degraded with the temporal envelope intact, individuals obtained good speech recognition scores in quiet. In the presence of noise, the temporal modulations of the target speech reduces as the noise fills in the peaks and troughs of the temporal waveform of the speech signal (Baer & Moore, 1993; Drullman, 1995). Maskers like speech shaped noise which are enveloped by similar temporal information as the target speech degrade the temporal envelope of the target even further, resulting in poor perception in noise. With the increase in the intensity of the masker, ‘listening in dips’ becomes more difficult and SPIN scores reduces further (Cooke, 2006).

Hence, the findings of our study that the SPIN scores reduce as the SNRs become poor can be justified by the decrease in the depth of temporal modulation of the envelope of speech with the increase in noise leading to loss of information.

4.3 Across Channel Gap Detection Test

Across Channel (AC) GDT values for each ear was tabulated in SPSS v20. Descriptive analysis was carried out. The mean AC GDT value was found to be 35.89 (Standard Deviation:11.98) and median was 33.5. The thresholds ranged from 19 to 66.8. This shows the large individual variability in utilizing temporal resolution skills in individuals with normal hearing sensitivity. Similar results were also obtained by previous investigators (Phillips & Smith, 2004; Phillips et al., 2010 and Hess et al., 2012).

Literature review suggested that there is a lot of variability in AC GDT for NBN than within channel (WC) GDT for NBN in individuals with normal hearing sensitivity because AC GDT activates two perceptual neural channels and the detection of the silence is dependent on the relative timing of deactivation of neural activity in one channel due to the offset of the lead marker and activation of neural firing in another channel due to onset of the lag marker (Phillips et al.,2010). This comparison across two neural channels to detect the silence requires highly precise temporal processing skills.

This also makes the task difficult, increasing the gap detection thresholds with respect to within channel GDT which activates only one neural channel. This could be the reason for the wide range of AC GDT values obtained in the current study.

4.4 Auditory Brainstem Response (ABR)

ABR was evaluated for click stimuli, at the intensities of 80 dB nHL, 60 dB nHL, 50 dB nHL and 40 dB nHL. At 80 and 60 dB nHL, the ABR responses were obtained at the repetition rates of 11.1/sec, 30.1 /sec, 70.1 /sec and 90.1 /sec, whereas, at 50 and 40 dB nHL, it was obtained at 30.1/sec. The following parameters of ABR were analysed:

1. Latency of wave I and wave V at different repetition rates across intensities.
2. Latency-Intensity function of wave V at the repetition rate of 30.1/sec
3. Duration of wave V at different repetition rates (11.1, 30.1, 70.1 and 90.1/sec), across the different intensities (80 and 60 dB nHL).
4. Slope of wave V at different repetition rates (11.1, 30.1, 70.1 and 90.1/sec), across the different intensities (80 and 60 dB nHL).
5. The inter-peak latencies of wave I-wave III, wave III-wave V and wave I-wave V at 80 dB nHL with the repetition rate of 11.1/sec.

4.4.1 Latency of wave I and wave V at different repetition rates across intensities

The latency of wave I and wave V across the repetition rates of 11.1/sec, 30.1 /sec, 70.1 /sec and 90.1 /sec at the four intensities of 80 dB nHL, 60 dB nHL, 50 dB nHL and 40 dB nHL was tabulated. The response rate of wave I and wave V were calculated for each of the conditions. Wave I had a low response rate at higher repetition rates (70.1 and 90.1/sec) even at high intensities, and it decreased with the decrease in intensity. Due to the low response rate at lower intensities, latency of wave I was measured and analysed at only 80 dB nHL across the different repetition rates. The table given below represents the response rate of wave I and wave V across repetition rates and intensities.

Table 4.2

Response rate of wave I and wave V (in percentage) across the repetition rates of 11.1/sec, 30.1 /sec, 70.1 /sec and 90.1 /sec at the intensities of 80 dB nHL, 60 dB nHL, 50 dB nHL and 40 dB nHL

Stimulus condition	Response Rate (in percentage)							
Intensity(dB nHL)/ Repetition Rate	11.1		30.1		70.1		90.1	
	I	V	I	V	I	V	I	V
80	100	100	96.67	100	33.33	100	15	100
60	13.33	100	3.33	100	3.33	100	0	100
50	-	-	0	100	-	-	-	-
40	-	-	0	100	-	-	-	-

Wave I had lower response rate with the increase in the repetition rate and reduction in intensity. In studies by Rowe (1978), Chiappa et al. (1979), Stockard et al. (1979) and Suzuki et al. (1985), wave I was identified and marked upto intensity of 60 dB nHL and repetition rate of 80/sec. The reduction in the response rate with the increase in the repetition rate and decrease in intensity could be due to the adaptation of neurons, leading to reduced neural activity. Also, the auditory neurons may undergo metabolic changes at the cellular level leading to poor synchronous firing (Don et al., 1977).

In the present study, the decrease in the response rate of wave maybe explained due to the reduction in the amplitude of wave I resulting from poor neural synchrony leading to indiscernible wave I at higher repetition rates and lower intensities.

Wave I

Descriptive statistics was performed on the latency values of wave I. Table 4.3 represents the mean, standard deviation, median, maximum and minimum values of wave I latency.

Table 4.3

Mean, SD, median, maximum and minimum values of latency of wave I obtained at 80 dB nHL, across repetition rates

Repetition rate	Mean (in msec)	SD (in msec)	Median (in msec)	Minimum (in msec)	Maximum (in msec)
11.1/sec	1.65	0.12	1.65	1.5	1.9
30.1/sec	1.68	0.09	1.68	1.57	1.8
70.1/sec	1.78	0.11	1.81	1.6	1.9
90.1/sec	1.99	0.12	2.02	1.8	2.15

It was seen that with increase in repetition rate, there was an increase in the mean and median latency of wave I. This shift in latency was greater with the increase from the repetition rate to 70.1 to 90.1/sec. This can be clearly visualized in Figure 4.1.

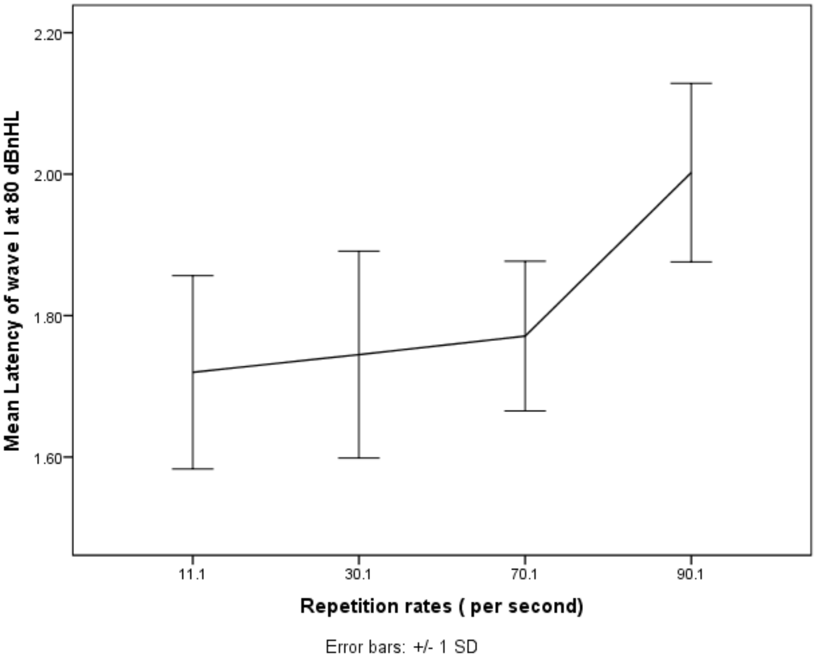

Figure 4.1 Latency- repetition rate function of wave I measured at 80 dB nHL.

Friedman test was executed, and it was observed that there was a statistically significant difference in latency of wave I at 80 dB nHL across repetition rates, $\chi^2(3) = 18.43$, $p = 0.00$, that is, the latency of wave I increased significantly with the increase in the repetition rate.

Post- hoc analysis with Wilcoxon Signed Rank test was performed to examine the pair of the repetition rates to have significant difference in the latency. At the intensity of

80 dB nHL, there was a significant difference ($p<0.05$) in the latency of wave I across all the pairs of repetition rates. The results of the test are given in Table 4.4.

Table 4.4

Results of Wilcoxon Signed Rank test with Test Statistic (Z) and significance values for latency of wave I measured at 80 dB nHL across the pairs of repetition rates

Repetition Rate pairs	Z value	*p* values
30.1/sec- 11.1/sec	-3.094	0.002
70.1/sec-11.1/sec	-3.216	0.001
90.1/sec-11.1/sec	-2.668	0.008
70.1/sec-30.1/sec	-3.032	0.002
90.1/sec-30.1/sec	-2.670	0.008
90.1/sec-70.1/sec	-2.207	0.027

The above results show that there is an increase in the latency of wave I with the increase in repetition rate, with the effect more pronounced after the repetition rate of 70.1/sec.

Previous studies also show that with increase in the repetition rate, the latency of wave I increases (Rowe, 1978; Chiappa et al.,1979, Stockard et al.,1979 and Suzuki et al.,1985). The justification for this finding was that the neurons at the level of inner hair cell and the auditory nerve junction undergo adaptation due to metabolic changes (Don et al., 1977) with the increase in the repetition rate. The neurons start firing at a higher rate when the stimulus is presented, but as the stimulus progresses, the spike rate of the individual neurons reduces, which may increase the latency of the wave when the total neuronal activity is considered over time (Sumner & Palmer, 2012). This justification holds true for the present study as well, as there is an increase in latency of wave I with the increase in repetition rate has been observed.

Wave V:

Descriptive statistics was performed on the latency values of wave V. The mean, standard deviation, median, maximum and minimum values obtained are given below in the Table 4.5.

Table 4.5

Mean, SD, median, maximum and minimum values of latency of wave V measured at 80 dB nHL and 60 dB nHL, across repetition rates

	Mean (in msec)		SD (in msec)		Median (in msec)		Minimum (in msec)		Maximum (in msec)	
RR / Intensity	80	60	80	60	80	60	80	60	80	60
11.1	5.5	6.06	0.23	0.25	5.47	6.03	4.92	5.6	6.10	6.80
30.1	5.66	6.25	0.23	0.27	5.63	6.28	5.13	5.75	6.42	6.97
70.1	5.99	6.55	0.26	0.29	5.98	6.54	5.42	6.13	6.65	7.45
90.1	6.09	6.73	0.25	0.32	6.09	6.79	5.50	6.15	6.67	7.78

The table depicts the trend of increase in mean and median latency of wave V with the increase in the repetition rate at both 80 and 60 dB nHL. The same is displayed in Figure 4.2 and Figure 4.3. It can be noticed from the figures that the latency shift for wave V across the repetition rates is almost uniform, unlike the increase in the latency shift (steeper slope) from 70.1 to 90.1/sec repetition rate for wave I.

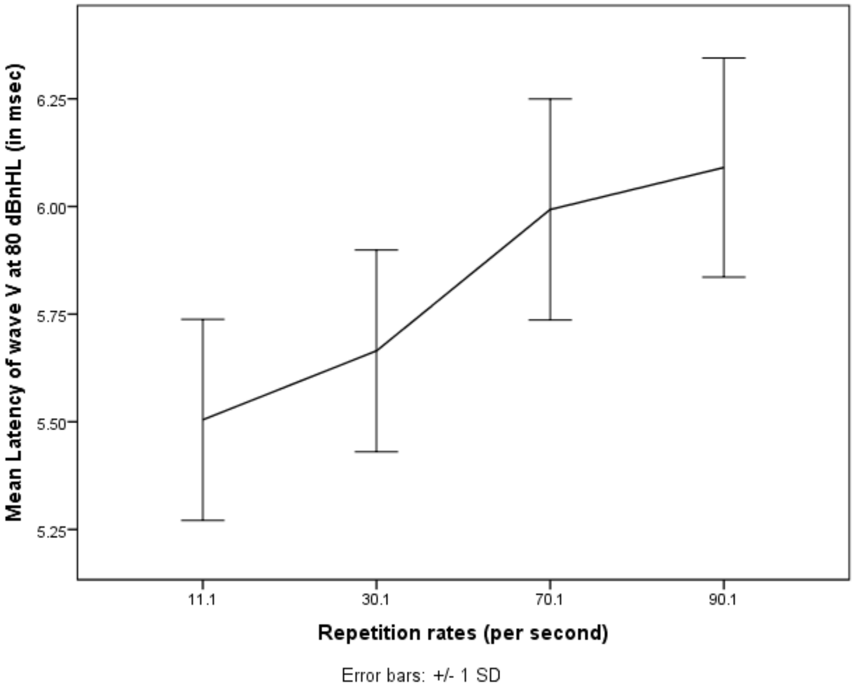

Figure 4.2 Latency- repetition rate function of wave V obtained at 80 dB nHL.

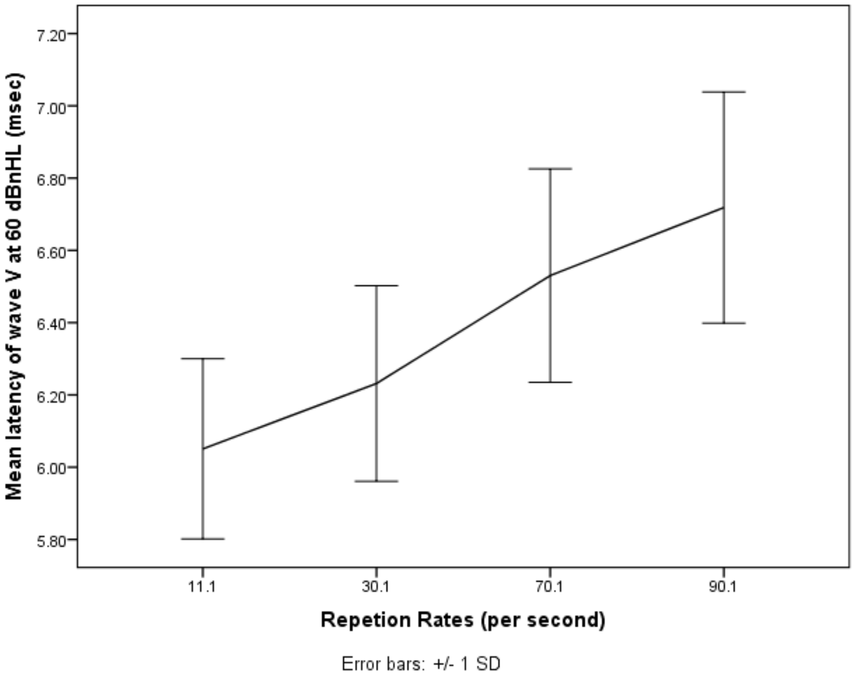

Figure 4.3 Latency- repetition rate function of wave V measured at 60 dB nHL.

Friedman test was administered independently at the intensities of 80 and 60 dB nHL to check whether repetition rate has a significant effect on the latency of wave V. It revealed a significant effect on the latency of wave V, $\chi^2(3) = 169.49$, $p = 0.00$, at 80 dB nHL, and $\chi^2(3) = 176.89$, $p = 0.00$, at 60 dB nHL. Hence, latency of wave V increased significantly with the increase in the repetition rate at both the intensities.

As the Friedman test revealed significant difference in the latency of wave V across the repetition rates, Wilcoxon Signed Rank test was performed to examine the pair of the repetition rates to have significant difference in the latency. There was a significant difference ($p<0.01$) in the latency of wave V across all the pairs of repetition rates at 80 and 60 dB nHL. The results of the tests are given in Table 4.6.

Table 4.6

Results of Wilcoxon Signed Rank test with Test Statistic (Z) and significance values for latency of wave V obtained at 80 and 60 dB nHL across the pairs of repetition rates

	Z values		*p* values	
RR pairs/ Intensity	80	60	80	60
30.1/sec- 11.1/sec	-5.77	-6.68	0.000	0.000
70.1/sec-11.1/sec	-6.74	-6.74	0.000	0.000
90.1/sec-11.1/sec	-6.74	-6.74	0.000	0.000
70.1/sec-30.1/sec	-6.74	-6.74	0.000	0.000
90.1/sec-30.1/sec	-6.74	-6.74	0.000	0.000
90.1/sec-70.1/sec	-5.5	-6.5	0.000	0.000

Previously, Don et al. (1977), Rowe (1978), Chiappa et al. (1979), Stockard et al. (1979), Ballachanda, Moushegian and Stillman (1992) and Suzuki et al. (1985) studied the effects of repetition rate of the amplitude and latency of waves of ABR and found that with increase in the repetition rate, latency and amplitude of wave V increases and decreases respectively. These authors have explained the results due to the adaptation of the neurons along the auditory pathway with the increase in the repetition rate. With stimulus presentation over time or with stimulus taxing the auditory system, the individual neurons decrease their firing rate, resulting in an overall reduction of neuronal discharge (Sumner & Palmer, 2012).

Don et al. (1977) described the effect of adaptation of neurons on the latency of waves of ABR in two ways. One, the change in the modal frequency of the neurons shifting the peak of the wave and two, reduction in the neural activity of a dominant set of fibres at the generation site, leading to prolonged latencies.

Another contributing factor to the prolonged latency of wave V can be due to the increased latency of wave I, due to adaptation at the junction of inner hair cell-auditory nerve (site of generation of wave I). This in turn leading to prolonged conduction time of the stimulus to the generation site of wave V. The above reasons explain the prolongation of wave V latency with the increase in repetition rate.

4.4.2 Latency-Intensity function of wave V at the repetition rate of 30.1/sec

The latency-intensity function of wave V was plotted at the repetition rate of 30.1/sec. The repetition rate of 30.1/sec was chosen as literature has shown no significant effect of repetition rate on the latency of wave V upto 50/sec (Paludetti, Maurizi, & Ottaviani, 1983). Also, clinically, 30.1/sec repetition rate is widely used. With these two reasons, the latency-intensity function was analysed at the repetition rate of 30.1/sec. Wave I was not considered for this parameter as the response rate of wave I decreased with the decrease in intensity, as shown in Table 4.2.

Descriptive analysis revealed that the mean and median latency of wave V increased with decrease in the intensity, as displayed in Table 4.7. The Figure 4.4 showcasing the latency-intensity function reveals that the maximum latency shift (steeper slope) was seen when the intensity changed from 80 to 60 dB nHL.

Table 4.7

Mean, SD, median, maximum and minimum values of latency of wave V quantified at 30.1/sec across intensities

Intensity	Mean (in msec)	SD (in msec)	Median (in msec)	Minimum (in msec)	Maximum (in msec)
80	5.66	0.23	5.63	5.13	6.42
60	6.25	0.27	6.28	5.75	6.97
50	6.57	0.31	6.59	6.08	7.65
40	7.03	0.29	7.03	6.47	7.88

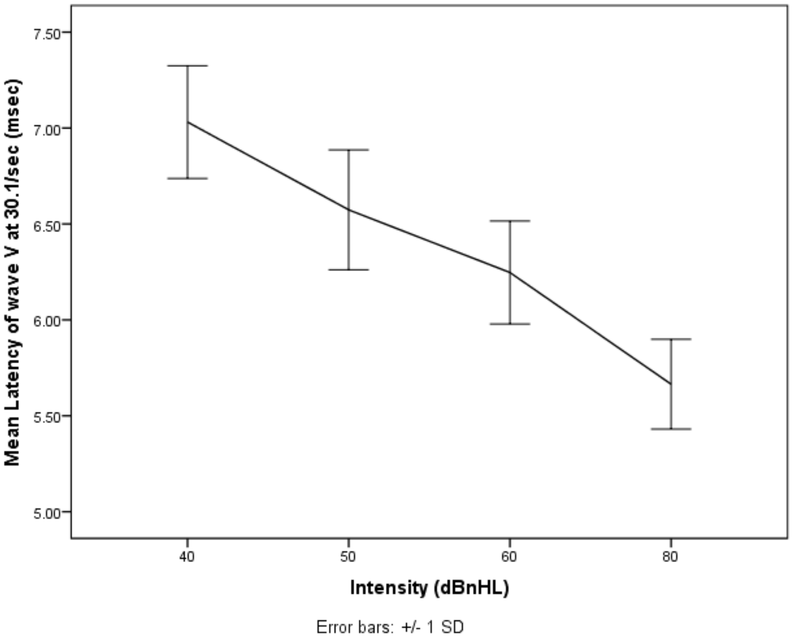

Figure 4.4 Latency- intensity function of wave V obtained at 30.1/sec.

As seen in the Figure 4.4, the latency shift from 80 to 60 dB nHL was steeper and may be due to the intensity change of 20 dB nHL from 80 dB nHL to 60 dB as opposed to 10 dB nHL for the other intensity changes.

As reported previously by Don et al.(1977), Chiappa et al. (1979) and Stockard et al.(1979), the latency of wave V increased with the decrease in intensity. This finding was justified with the fact that auditory nerve consists of low and high spontaneous rate fibres. At the higher intensities, both type of fibres will be activated, giving rise to earlier latencies, whereas, at lower intensities (40 dB nHL), only the high spontaneous rate fibres will be firing leading to increased latency values.

With the increase in intensity, the excitation pattern of basilar membrane becomes highly non linear and leading to response from the entire basilar membrane (Davis, 1983). This may lead to earlier latencies of waves.

The above explanation would explain the finding of increase in latency of wave V with the decrease in intensity in the present study as well.

4.4.3 Duration of wave V across intensities, at different repetition rates

The duration of wave V was calculated from the end of wave III to the end of wave V, as the presence of wave IV is ambiguous even in individuals with normal hearing sensitivity. Descriptive analysis showed that there was a trend of increase in the mean duration of wave V and median value with the increase in the repetition rate at 80 and 60 dB nHL (displayed in Table 4.8). The same is displayed in Figures 4.5 and 4.6.

Table 4.8

Mean, SD, median, maximum and minimum values of duration of wave V calculated at 80 dB nHL and 60 dB nHL, across repetition rates

	Mean (in msec)		SD (in msec)		Median (in msec)		Minimum (in msec)		Maximum (in msec)	
RR/ Intensity	80	60	80	60	80	60	80	60	80	60
11.1	1.99	2.08	0.23	2.08	1.95	2.09	1.43	1.45	2.47	2.75
30.1	2.10	2.04	0.24	2.04	2.08	2.02	1.67	1.10	2.75	2.82
70.1	2.28	2.08	0.32	2.08	2.22	2.05	1.48	1.45	3.17	2.57
90.1	2.35	2.23	0.29	2.23	2.3	2.26	1.44	1.75	3.02	2.65

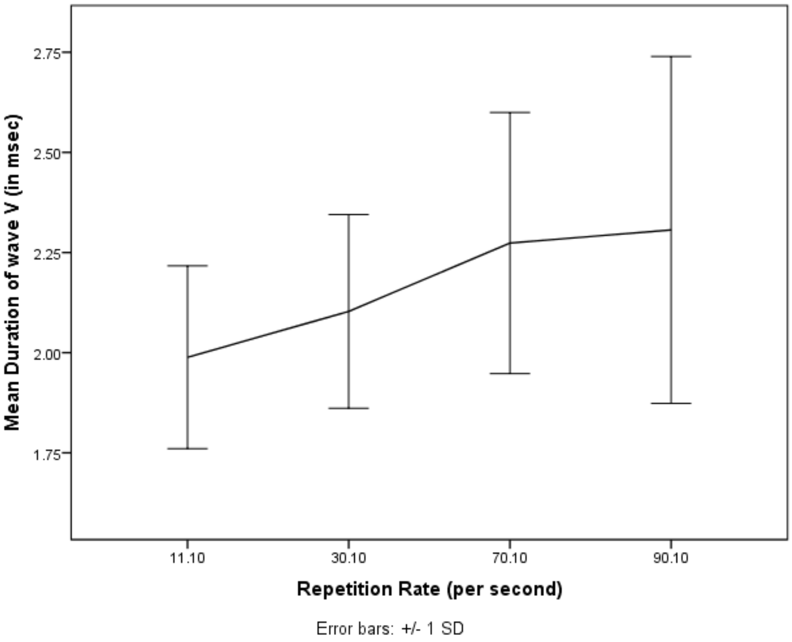

Figure 4.5 Duration of wave V- repetition rate function obtained at 80 dB nHL.

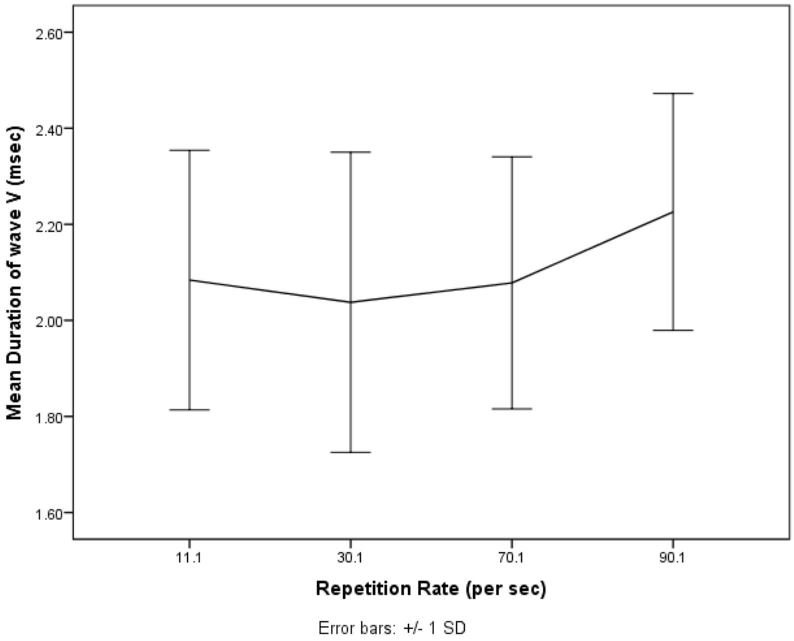

Figure 4.6 Duration of wave V- repetition rate function measured at 60 dB nHL.

The figures above also show the large individual variability of neural coding to different repetition rates at the two intensities.

Friedman test was performed to check for any significant effect of repetition rates on the duration of wave V, at two intensities, 80 and 60 dB nHL, independently. At 80 dB nHL, the Friedman test exhibited significant difference, $\chi^2(3) = 49.69$, $p = 0.00$ across the repetition rates, and hence, Wilcoxon Signed Rank test was executed to check for the pair-wise significant differences for duration of wave V. A significant difference for all the pairs of repetition rates assessed was observed. The results for Wilcoxon Signed Rank test are displayed in Table 4.9.

At 60 dB nHL, the Friedman test showed significant difference, $\chi^2(3) = 15.98$, $p = 0.001$ across the repetition rates. For the post hoc analysis, Wilcoxon Signed Rank test was performed to check for the pair-wise significant differences for duration of wave V.

It was seen that there were significant difference ($p<0.05$) between most of the the pairs of repetition rates. The results for Wilcoxon Signed Rank test are displayed in Table 4.9. It shows that there is a significant increase in the duration of wave V beyond the repetition rate of 70.1/sec at 60 dB nHL.

Table 4.9

Results of Wilcoxon Signed Rank test with Test Statistic (Z) and significance values for duration of wave V at 80 and 60 dB nHL

	Z values		*p* values	
RR pairs / Intensity	80	60	80	60
30.1/sec- 11.1/sec	-3.69	-0.83	0.000	0.406
70.1/sec-11.1/sec	-4.8	-0.18	0.000	0.868
90.1/sec-11.1/sec	-4.72	-1.99	0.000	0.047
70.1/sec-30.1/sec	-4.3	-1.0	0.000	0.317
90.1/sec-30.1/sec	-4.4	-2.30	0.000	0.021
90.1/sec-70.1/sec	-2.53	-2.76	0.011	0.006

The literature reviewed revealed no prior studies have considered duration of wave V as a parameter to analyse with the change in repetition rate. This finding may be explained due to the reduction in neural firing caused by adaptation of neurons and diminished neural synchrony with increase in repetition rate (Fowler & Noffsinger, 1983; Rowe, 1978; Chiappa et al., 1979; Stockard et al., 1979; Suzuki et al., 1985) along the auditory pathway. This leads to a prolongation in latency of wave III and wave V, resulting in increased duration of wave V.

With the decrease in intensity from 80 to 60 dB nHL, the number of active neurons reduced. Also, there is diminished synchrony of firing which is more pronounced at lower intensities (Don et al.,1977; Chiappa et al.,1979 and Stockard et al.,1979).This lack of synchronous firing also leads to the increase in duration of the peak.

4.4.5 Slope of wave V at intensities of 80 and 60 dB nHL at different repetition rates

The slope of wave V was calculated by measuring the peak amplitude of the wave V and dividing it by the time taken for the wave to reach its trough from the peak (Gopal & Kowalski, 1999). This was determined at 80 and 60 dB nHL and also at different repetition rates, and was tabulated in SPSS v20. Descriptive analysis was conducted for the slope measures of wave V. The mean, standard deviation, median, maximum and minimum values of slope of wave V at 80 dB nHL and 60 dB nHL, across repetition rates are displayed in Table 4.10.

Table 4.10

Mean, SD, median, maximum and minimum values of slope of wave V at 80 dB nHL and 60 dB nHL across repetition rates

	Mean (in msec)		SD (in msec)		Median (in msec)		Minimum (in msec)		Maximum (in msec)	
RR/ Intensity	80	60	80	60	80	60	80	60	80	60
11.1	0.87	0.68	0.27	0.21	0.87	0.63	0.34	0.26	1.40	1.40
30.1	0.79	0.67	0.32	0.22	0.75	0.68	0.18	0.22	2.19	1.43
70.1	0.69	0.58	0.28	0.24	0.65	0.52	0.33	0.20	1.76	1.26
90.1	0.65	0.54	0.24	0.21	0.62	0.49	0.19	0.17	1.57	1.46

The table shows a trend of decrease in the mean and median slope of wave V with the increase in the repetition rate. There is also a large individual variability in the slope of wave V which may be due to the differences in coding of stimulus across intensities at different repetition rates. The same can be observed in Figures 4.7 and 4.8.

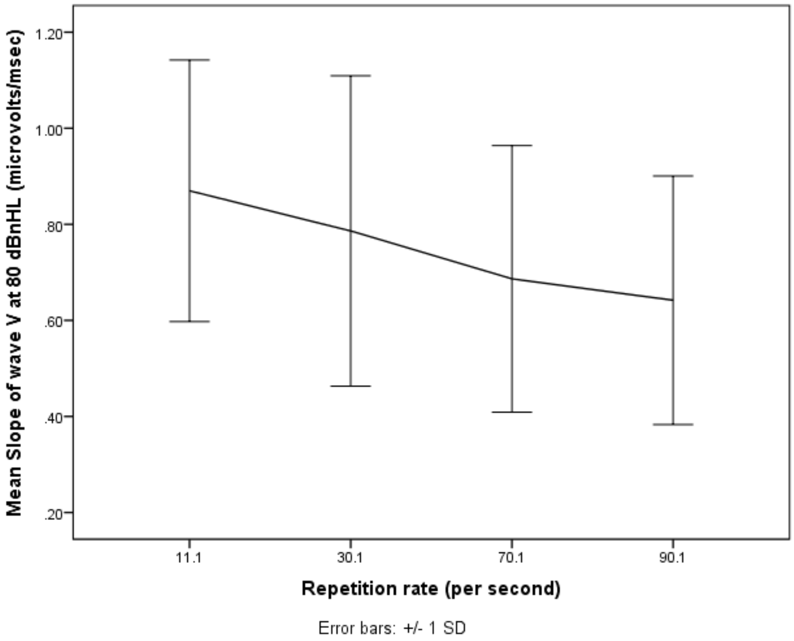

Figure 4.7 Slope of wave V- repetition rate function at 80 dB nHL.

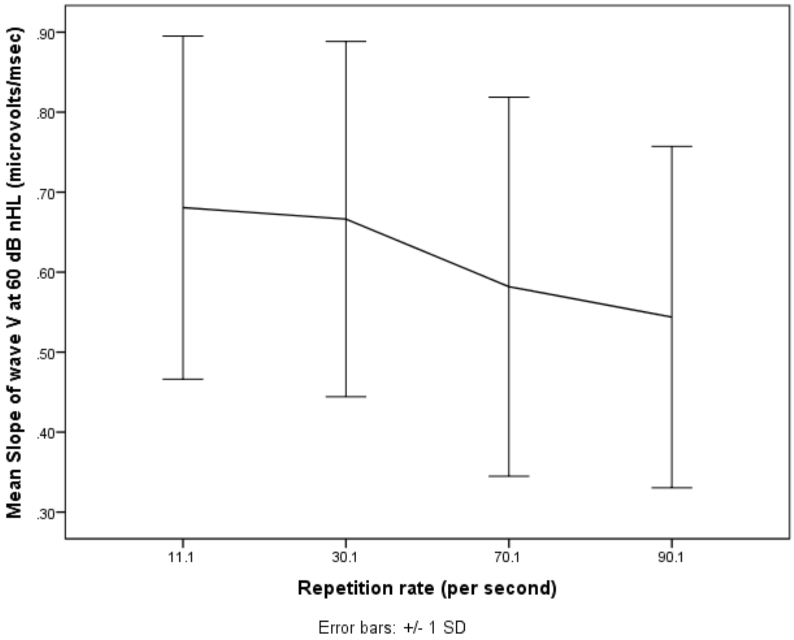

Figure 4.8 Slope of wave V- repetition rate function at 60 dB nHL.

To analyse if the decrease in the slope of wave V across repetition rates was significant, Friedman test was executed to inspect the significant effect of repetition rate on slope of wave V at the intensities of 80 and 60 dB nHL, independently.

At 80 dB nHL, the Friedman test exhibited significant difference, $\chi^2(3) = 43.79$, $p = 0.000$ across the repetition rates, and hence, Wilcoxon Signed Rank test was performed to check for the pair-wise significant differences for duration of wave V. It was observed that all the pairs of repetition rates differed significantly, except for the pair of 70.1-90./sec. The results for Wilcoxon Signed Rank test are displayed in Table 4.16 (dark shaded boxes indicate no significant difference).

At 60 dB nHL, the Friedman test showed significant difference, $\chi^2(3) = 49.39$, $p = 0.000$ across the repetition rates, and hence, Wilcoxon Signed Rank test was performed to check for the pair-wise significant differences for duration of wave V. It was seen that there were significant difference ($p<0.05$) between the pairs of repetition rates of 70.1/sec-11.1/sec,90.1/sec-11.1/sec, 70.1/sec-30.1/sec and 90.1/sec-30.1/sec, whereas, there was no significant difference between the other 30.1/sec- 11.1/sec and 90.1/sec-70.1/sec. The results for Wilcoxon Signed Rank test are displayed in Table 4.11 (dark shaded boxes indicate no significant difference).

Table 4.11

Results of Wilcoxon Signed Rank test with Test Statistic (Z) and significance values for slope of wave V at 80 dB nHL and 60 dB nHL across pairs of repetition rates

	Z values		*p* values	
RR pairs / Intensity	80	60	80	60
30.1/sec- 11.1/sec	-3.63	-0.78	0.000	0.438
70.1/sec-11.1/sec	-5.18	-4.03	0.000	0.000
90.1/sec-11.1/sec	-5.29	-4.73	0.000	0.000
70.1/sec-30.1/sec	-3.44	-3.29	0.000	0.001
90.1/sec-30.1/sec	-3.79	-4.88	0.000	0.000
90.1/sec-70.1/sec	-1.77	-1.78	0.077	0.075

The table above shows that there is a significant decrease in the slope of wave V with the increase in repetition rate, but no differences are found between the higher repetition rates at both intensities. The literature review revealed no prior studies have considered slope of wave V as a parameter to observe the effect of repetition rate.

The slope of wave V decreases with the increase in repetition rate, as the neural activity reduces at higher repetition rates due to adaptation and decreased neural firing (Fowler & Noffsinger, 1983; Rowe, 1978; Chiappa et al., 1979; Stockard et al., 1979; Suzuki et al., 1985) leading to prolonged onset and offset of wave V.

With the decrease in intensity from 80 to 60 dB nHL, the number of active neurons reduces (Don et al.,1977; Chiappa et al.,1979 and Stockard et al.,1979) and leads to diminished synchrony of firing which is more pronounced at lower intensities. Thus, the poor synchronous firing leads to broadening of peak and reduction in amplitude of wave V. This results in decrease in slope of wave V with the decrease in intensity and increase in repetition rate as it is calculated by amplitude of wave V divided by duration of negative slope of wave V.

4.4.6 Interpeak Latency differences

The inter-peak latency differences were tabulated for wave I-wave III, wave III-wave V and wave I-wave V obtained at 80 dB nHL for repetition rate of 11.1/sec. This condition was chosen since the response rate was 100% for all the three waves.

Descriptive analysis was performed on the inter peak latency differences. The mean, standard deviation, median, minimum and maximum values of the IPL is shown in Table 4.12.

Table 4.12

Mean, SD, median, maximum and minimum values of inter-peak latency differences at 80 dB nHL for repetition rate of 11.1/sec

Inter-peak intervals	Mean (in msec)	SD (in msec)	Median (in msec)	Minimum (in msec)	Maximum (in msec)
I-III	2.04	0.16	2.03	1.77	2.87
III-V	1.75	0.19	1.77	1.19	2.12
I-V	3.79	0.21	3.8	3.24	4.20

From the table above, it can be observed that the minimum IPL difference was seen between the waves III and V and the maximum was between waves I and V. Chiappa et al. (1979) and Stockard et al. (1979) also reported IPL at lower repetition rate and obtained similar results. The same is showcased in Figure 4.9.

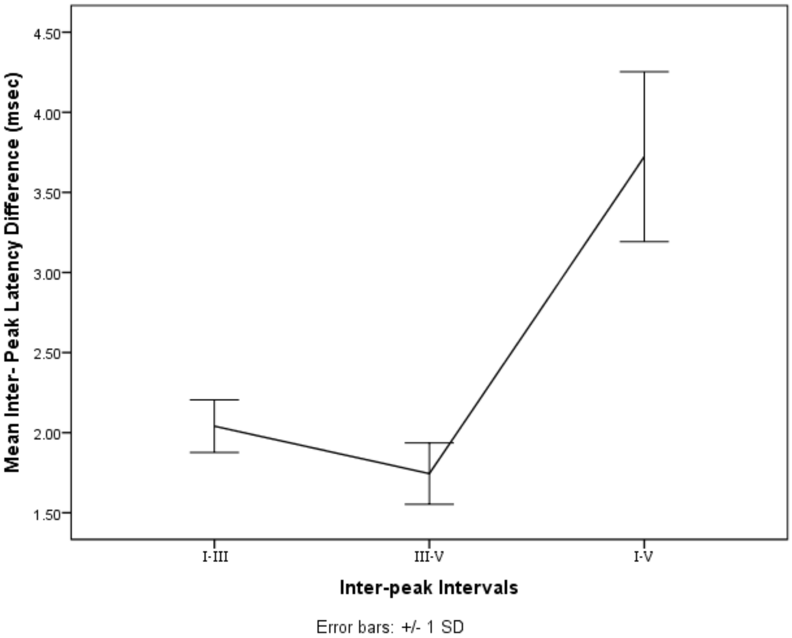

Figure 4.9 Inter-peak latency differences at 80 dB nHL for repetition rate of 11.1/sec.

Friedman test was performed to analyse if there was any significant difference across the different waves, and a significant difference, $\chi^2(3) = 106.04$, $p = 0.000$ was observed. Therefore, Wilcoxon Signed Rank test was performed to check for pair-wise significant differences. The test exhibited that all the pairs had significant differences ($p<0.01$). The results for Wilcoxon Signed Rank test are displayed in Table 4.13.

Table 4.13

Results of Wilcoxon Signed Rank test with Test Statistic (Z) and significance values for Inter-peak Latency differences at 80 dB nHL, for the repetition rate of 11.1/sec

IPL	Z values	*p* values
Wave III and V- Wave I and III	-5.93	0.000
Wave I and V- Wave I and III	-6.68	0.000
Wave I and V- Wave III and V	-6.73	0.000

Previous studies (Chiappa et al.,1979 and Stockard et al.,1979) have not reported of pair wise comparisons between sets of waves for interpeak latency differences for a single condition. Also, we expected no significant difference for the comparison of interpeak latency differences for the sets of wave I-III and wave III-V, as the latency difference of wave I to wave III and wave III to wave V is to be of a similiar and fixed interval.

The above finding of significant differences across the pairs of waves for IPL may be due to the differences in the neural activity generated at the different generation sites of each of the waves. Wave I is generated by cochlear and neural potentials whereas wave III and wave V are generated purely by neural potentials (Fowler & Noffsinger, 1983). Hence leading to slower conduction of stimulus from wave I to wave III as compared to wave III to wave V giving rise to different inter peak latency differences.

4.5 CORRELATIONAL ANALYSIS

The main aim of the present study was to evaluate the relationship between speech perception in noise scores and some aspects of temporal processing which was assessed using AC GDT and ABR, in individuals with normal hearing sensitivity. To attain this aim, correlation was obtained using Spearman's rank-order correlation on the following parameters:

1. SPIN scores and Across Channel Gap detection threshold
2. SPIN scores and the different temporal parameters of ABR

4.5.1 SPIN Scores and Across Channel Gap Detection Threshold (AC GDT)

The analysis revealed that there is a significant negative correlation, r_s= -0.54, *p*=0.00 between SPIN scores obtained at -5dB SNR and Across Channel Gap detection threshold. No correlation was seen between AC GDT and SPIN scores at 0 dB SNR (r_s= -0.14, *p*=0.274) and -3 dB SNR (r_s= -0.23, *p*=0.082). It can be observed that level of negative correlation increases as the SNR reduces.

The Figure 4.10 shows the correlation values of AC GDT and SPIN at different SNRs. It can be seen that there is a significant negative correlation between AC GDT and SPIN at -5 dB SNR.

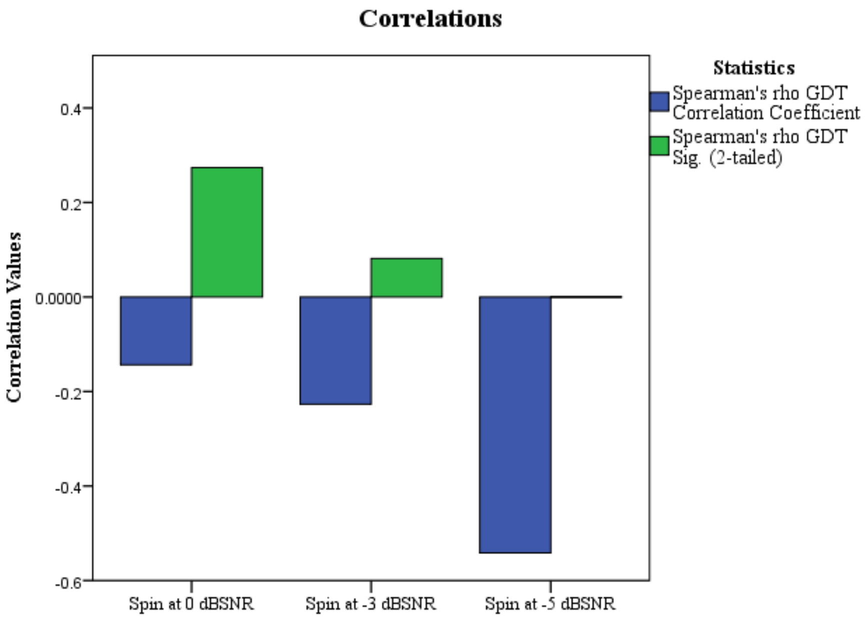

Figure 4.10 Graph representing correlation values between AC GDT and SPIN scores at 0, -3 and -5 dB SNR.

The results suggest that there is a significant increase in the SPIN scores with the improvement in the AC GDT, that is, when the AC GDT values are more in individuals with normal hearing sensitivity, they are likely to have more difficulty in perception of speech in adverse listening conditions, like in noise. Though there is no significant correlation between AC GDT and speech perception in relatively favourable conditions (0 and -3 dB SNRs), correlation values increased with the decrease in SNR. This suggests that AC GDT values are better predictors of SPIN with the decrease in SNRs.

Studies by Papakonstantinou et al. (2011), Helfer and Vargo (2009) and Summers et al. (2013) used different tests to assess temporal resolution like amplitude modulation, gaps in noise, temporal masking and correlated the findings with the scores of speech perception in noise. They found correlation between the temporal resolution measures and speech perception in noise scores. They stated that for speech perception in noise, the ability for the person to ‘listen in dips’ is highly important. They have also stressed on the fact that speech performance was not dependent on audibility, but on the temporal processing abilities.

Walker et al. (2011) found that AC GDT correlates with reading performance. They concluded that the relative timing of two or more perceptual tasks is very important for phonological awareness, and reflected in the reading abilities.

Elangovan and Stuart (2008) have stated that AC GDT highly correlates with voice onset time phonetic boundary. Within Channel GDT showed no correlation. VOT is the temporal cue responsible of categorical perception between voiced and unvoiced sounds. They have suggested that one of the psychophysical perceptual aspects responsible for the categorical perception of VOT may be AC GDT.

This implies that temporal resolution plays an important role in speech perception in noise, especially when the SNR is poor. Similar results have been reported by previous investigators showing temporal resolution is essential for perception in adverse listening conditions (Fitzgibbons & Wightman, 1982; Glasberg & Moore, 1989; Gordon-Salant & Fitzgibbons, 1993).

4.5.2 SPIN Scores and the parameters of ABR

The correlation between SPIN scores and the different parameters of ABR established is given below:

- Latency of wave I and wave V at different repetition rates across intensities.

- The slope (latency shift per dB nHL) of the latency intensity function of wave V at the repetition rate of 30.1/sec across the intensities of 80, 60, 50 and 40 dB nHL.
- Duration of wave V at different repetition rates (11.1, 30.1, 70.1 and 90.1/sec), across the different intensities (80, 60, 50 and 40 dB nHL).
- Slope of wave V at different repetition rates (11.1, 30.1, 70.1 and 90.1/sec), across the different intensities (80 and 60 dB nHL).
- The inter-peak latencies of wave I-wave III, wave III-wave V and wave I-wave V at 80 dB nHL with the repetition rate of 11.1/sec.

4.5.2.1 Correlation between scores and the latency of wave I and wave V obtained at the different repetition rates and intensities

Wave I

Here, latency of wave I was considered only at 80 dB nHL at the different repetition rates, as the response rate of wave I decreased with the decrease in intensity (displayed in Table 4.2).

Correlation between the two parameters was established using Spearman's rank-order correlation and revealed a significant negative correlation ($p<0.05$) between SPIN scores at 0 dBSNR and Latency of wave I at a repetition rate of 70.1/sec. There was no correlation present between other conditions of SPIN and Latency of wave I obtained at different repetition rates. Results are displayed in Table 4.14 (dark shaded boxes indicate no significant correlation).

Table 4.14

Results of Spearman's rank-order correlation, r_s *and significance values for SPIN scores and latency of wave I obtained at 80 dB nHL at different repetition rates*

Repetition rates/ SNRs		11.1/sec	30.1/sec	70.1/sec	90.1/sec
0 dBSNR	r_s values	-0.074	-0.117	-0.476*	0.287
	p values	0.576	0.383	0.034	0.454
-3 dBSNR	r_s values	0.151	0.039	-0.135	0.223
	p values	0.250	0.770	0.572	0.564
-5 dBSNR	r_s values	-0.087	-0.144	-0.066	0.624
	p values	0.511	0.279	0.783	0.073

Latency of wave I is relatively not affected by repetition rate as seen in Section 4.4.1. Pratt and Somher (1976) also reported that latency of wave I is resilient to change in repetition rate. This might have led to lack of correlation between SPIN scores at different SNRs and latency of wave I. The negative correlation obtained at repetition rate of 70.1/sec could just be a chance factor. Hence, latency of wave I may not be a sensitive measure for prediction of SPIN abilities.

Wave V

Spearman's rank-order correlation revealed no correlation ($p>0.05$) between SPIN scores at all SNR conditions and Latency of wave V at the different repetition rates of 11.1, 30.1, 70.1 and 90.1/sec and at intensities of 80, 60 dB nHL and at intensities of 50 and 40 dB nHL at 30.1/sec repetition rate.

Table 4.15

Results of Spearman's rank-order correlation, r_s and significance values for SPIN scores and latency of wave V at 80 and 60 dB nHL at different repetition rates

Intensity	RR/SNR		11.1/sec	30.1/sec	70.1/sec	90.1/sec
80 dB nHL	0 dBSNR	r_s values	0.09	-0.07	-0.02	-0.03
		p values	0.48	0.619	0.899	0.838
	-3 dBSNR	r_s values	0.01	-0.1	-0.17	-0.06
		p values	0.96	0.434	0.185	0.644
	-5 dBSNR	r_s values	-0.04	-0.12	-0.12	-0.15
		p values	0.75	0.378	0.367	0.267
60 dB nHL	0 dBSNR	r_s values	-0.035	-0.097	-0.102	-0.153
		p values	0.791	0.462	0.437	0.242
	-3 dBSNR	r_s values	-0.236	-0.206	-0.111	-0.125
		p values	0.069	0.114	0.397	0.342
	-5 dBSNR	r_s values	-0.239	-0.148	-0.052	-0.113
		p values	0.065	0.261	0.696	0.389

Table 4.16

Results of Spearman's rank-order correlation, r_s and significance values for SPIN scores and latency of wave V at 50 and 40 dB nHL at 30.1/sec repetition rate

Intensity/ SNR		50 dB nHL	40 dB nHL
0 dBSNR	r_s values	-0.04	-0.11
	p values	0.736	0.393
-3 dBSNR	r_s values	-0.11	-0.05
	p values	0.402	0.683
-5 dBSNR	r_s values	-0.02	0.01
	p values	.885	0.969

A study by Papakonstantinou et al. (2011) found that chirp evoked ABR had correlation between wave V thresholds, sentence recognition in noise and temporal resolution measures. Hence, they concluded that temporal resolution abilities measured through behavioural and electrophysiological tests can predict the ability for perception of speech in noise.

Cunningham, Nicol, Zecker, Bradlow and Kraus (2001) conducted behavioural speech perception measures of just noticeable difference to the /da/-/ga/ continuum in quiet and in noise, click evoked ABR, speech evoked ABR to stimulus /da/ and cortical responses in typically developing children and children with learning problems. They observed a correlation between just noticeable differences in for conversational /da/-/ga/ continuum in noise and ABR wave V latency in noise. They reasoned the importance of neural synchrony to code for the temporal cues of speech. Study by King, Warrier, Hayes and Kraus (2002) conducted a similar study and also found a correlation between just noticeable differences for speech and FFR, but not with click evoked ABR. They have also attributed these findings to neural synchrony and its importance in perceiving speech in adverse conditions.

In the current study, there was no correlation obtained between SPIN scores at the different SNRs and latency of wave V across intensities of 80, 60 dB nHL at repetition rates of 11.1, 30.1, 70.1 and 90.1/sec; at intensities of 50 and 40 dB nHL at 30.1/sec repetition rate. This difference from previous studies may due to the difference in the stimulus considered. Papakonstantinou et al. (2011) had used chirp stimulus to elicit ABR, whereas Cunningham et al. (2001) and King et al. (2002) elicited ABR using click and speech stimulus, they also assessed the temporal resolution measures of just noticeable difference using speech. Hence, using speech as a stimulus for electrophysiological testing could be a better marker for predicting speech perception in noise, rather than non-speech stimuli like clicks.

4.5.2.2 SPIN scores at different SNR conditions and the slope of the latency-intensity function of wave V at 30.1/sec

To find the correlation between SPIN scores and slope of latency-intensity function of wave V, slope was measured by finding the difference in latency shift in consecutive intensities divided by the difference of the two consecutive intensities considered. Correlational analysis using Spearman’s rank-order correlation displayed no significant correlation (p>0.05) between SPIN scores at different SNR conditions and the slope of the latency-intensity function of wave V at 30.1/sec as shown in Table 4.17.

Table 4.17

Results of Spearman's rank-order correlation, r_s and significance values for SPIN scores and slope (latency shift/ dB nHL) of latency intensity function of wave V at 30.1/sec repetition rate

Intensity/ SNR		80-60	60-50	50-40	80-40
0 dBSNR	r_s values	-0.115	0.064	-0.140	-0.120
	p values	0.382	0.627	0.287	0.362
-3 dBSNR	r_s values	-0.226	0.138	-0.101	-0.110
	p values	0.083	0.293	0.443	0.402
-5 dBSNR	r_s values	-0.221	0.047	-0.034	-0.090
	p values	0.089	0.723	0.799	0.493

The table shows that there is no correlation between SPIN scores at different SNRs and the latency shift of slope V with the decrease in the intensity.

To the best of our knowledge, there is no study which compared the latency shift per dB nHL and correlated with SPIN scores. The lack of correlation in the current study could be due to the lack of correlation observed between SPIN scores and absolute latency of wave V at different repetition rates and across intensities. Therefore, the slope of latency intensity function of click evoked ABR may not predict speech perception in noise.

4.5.2.3 SPIN scores at different SNR conditions and duration of wave V obtained at different repetition rates and intensities

Spearman's rank-order correlation was performed for SPIN scores at all SNR conditions and duration of wave V at the repetition rates of 11.1, 30.1, 70.1 and 90.1/sec and at intensities of 80, 60 dB nHL and intensities of 50 and 40 dB nHL at 30.1/sec repetition rate.

Table 4.18

Results of Spearman's rank-order correlation, r_s and significance values for SPIN scores and duration of wave V at 80and 60 dB nHL at different repetition rates

Intensity	RR/ SNR		11.1/sec	30.1/sec	70.1/sec	90.1/sec
80 dB Nhl	0 dBSNR	r_s values	0.1	-0.11	-0.08	0.07
		p values	0.45	0.409	0.546	0.643
	-3 dBSNR	r_s values	-0.25	-0.19	0.08	0.02
		p values	0.052	0.143	0.551	0.905
	-5 dBSNR	r_s values	-0.13	0.04	0.03	-0.2
		p values	0.307	0.739	0.807	0.149
60 dB Nhl	0 dBSNR	r_s values	0.05	-0.17	-0.07	0.05
		p values	0.741	0.242	0.729	0.813
	-3 dBSNR	r_s values	0.16	-0.15	-0.22	-0.25
		p values	0.24	0.28	0.244	0.248
	-5 dBSNR	r_s values	0.18	-0.03	-0.17	-0.22
		p values	0.191	0.823	0.359	.302

Table 4.19

Results of Spearman's rank-order correlation, r_s and significance values for SPIN scores and duration of wave V at 50 and 40 dB nHL at the repetition rate of 30.1/sec

SPIN at different SNRs/ Intensity		50 dB nHL	40 dB nHL
0 dBSNR	r_s values	0.17	-0.06
	p values	0.361	0.758
-3 dBSNR	r_s values	-0.18	-0.2
	p values	0.325	0.328
-5 dBSNR	r_s values	0.14	0.09
	p values	0.463	0.668

The Tables 4.18 and 4.19 show that there is no correlation between SPIN scores and duration of wave V across the intensities at different repetition rates. Duration of wave V was calculated as the time taken for the neural activity to build up from the of trough of wave III, reach the peak of wave V and come down to the trough of wave V. Hence, this parameter is dependent on the absolute latency of trough of wave III, duration of wave IV, peak and trough of wave V. Till date, no study has correlated the duration of wave V and SPIN scores.

The duration of ABR waves is mainly dependent on synchronous firing of auditory neurons (Fowler & Noffsinger, 1983; Rowe, 1978; Chiappa et al., 1979; Stockard et al., 1979; Suzuki et al., 1985). So, increase in the duration of wave V is indicative of reduced neural synchrony. Therefore, a correlation between duration of wave V and SPIN scores was expected as neural synchrony is important for speech perception in noise (Anderson & Kraus, 2002). However, lack of correlation could be due to the inclusion of wave IV for the calculation of duration of wave V. Wave IV of ABR is more fragile and not discernible in many individuals with normal hearing sensitivity (Rowe, 1978). This property of wave IV made it difficult to accurately calculate the duration of wave V. This might have reduced the probability of duration of wave V correlating with speech perception in noise scores.

4.5.2.4 SPIN scores at different SNR conditions and slope of wave V at different repetition rates, at 80 and 60 dB nHL

At 80 dB nHL, significant positive correlation was exhibited on Spearman's rank-order correlation between SPIN scores at 0 dB SNR and slope of wave V at the repetition rates of 11.1/sec ($p<0.05$), 30.1/sec ($p<0.01$) and 70.1/sec ($p<0.01$). There was no significant correlation seen between SPIN scores at other SNR conditions and other intensity and repetition rate conditions of slope of wave V. Results are displayed in Table 4.20 (dark shaded boxes indicate no significant correlation).

At 60 dB nHL, significant positive correlation was seen on Spearman's rank-order correlation between SPIN scores at -3 dB SNR and slope of wave V at the repetition rate of 70.1/sec ($p<0.05$), and SPIN scores at -5 dB SNR and slope of wave V at the repetition rate of 70.1/sec ($p<0.01$) . There was no significant correlation seen between SPIN scores at other SNR conditions and other intensity and repetition rate conditions of slope of wave V. Results are displayed in Table 4.20 (dark shaded boxes indicate no significant correlation).

Table 4.20

Results of Spearman's rank-order correlation and significance values for SPIN scores and slope of wave V at 80 and 60 dB nHL at different repetition rates

RR/ SNR		11.1		30.1		70.1		90.1	
		80	60	80	60	80	60	80	60
0	r_s value	0.33	0.15	0.36	0.13	0.42	0.06	0.25	-0.05
	p value	0.011	0.253	0.004	0.312	0.001	0.641	0.056	0.726
-3	r_s value	0.02	-0.08	0.12	-0.08	-0.04	0.3	-0.04	0.18
	p value	0.87	0.529	0.38	0.522	0.763	0.022	0.777	0.179
-5	r_s value	0.23	0.03	0.21	0.21	0.19	0.37	0.15	0.17
	p value	0.08	0.796	0.104	0.114	0.144	0.004	0.25	0.190

Speech perception degrades in the presence of noise, and this has been attributed to the reduction of the neural synchrony in noise (Halls, 1992; Burkard and Sims, 2002 and Russo, Nicol, Musacchia & Kraus, 2004). But, the literature review revealed no prior studies conducted to explore the relationship between speech perception in noise and the slope of wave V with the increase in repetition rate and decrease in intensity for a click evoked ABR.

The above results suggest that for speech perception in noise for relatively favourable conditions (0 dB SNR) is positively correlated with slope of wave V at a higher intensity and upto repetition rates of 70.1/sec, that is, with the increase in slope of wave V, the SPIN scores also improve. It is also seen that the strength of correlation increases with the increase in repetition rate (Table 4.20).

The slope of wave V is decreased with the increase in repetition rate. It is well established that the synchronous firing plays a very important role in latency, amplitude and morphology of waves of ABR. With better synchrony of firing, the peak of the wave is sharper with increased amplitude (Rowe, 1977). Thus, poor synchrony would lead to reduced amplitude of wave V and broadening of peak. In the present study, the slope of wave V has been calculated as wave V amplitude divided by the duration of negative slope. Hence, reduction in the slope of wave V with the increase in the repetition rate is thus an indication of reduced synchronous firing with the increase in the repetition rate.. Poor synchrony of firing would have resulted in reduced amplitude of wave V with the increase in the negative slope and thereby reducing the value of slope with the increase in repetition rate.

In the current study, a positive correlation was obtained between the value of slope of wave V and SPIN scores, that is, as the value of slope decreases, the SPIN scores also decreased. This suggests that synchronous firing of auditory neurons is very essential for temporal processing of the input and hence speech perception, especially in adverse listening conditions. Anderson and Kraus (2002) also concluded from their study that neural synchrony is a key factor for speech perception in noise.Thus, it can be concluded that slope of wave V of ABR is a better marker to predict the speech perception abilities in individuals with normal hearing sensitivity.

Also, the calculation of slope of wave V was purely dependent on wave V morphology, unlike the parameter of duration of wave V considered in this study. The lack of correlation between duration of wave V and obtaining correlation with slope of wave V indicates that parameters which are totally dependent on wave V, and not on the other waves, like wave IV, could be a better predictor of speech perception in noise in individuals with normal hearing sensitivity.

4.5.2.5 SPIN scores at different SNR conditions and the inter-peak latencies

Spearman’s rank-order correlation was executed between the SPIN scores at the three SNR conditions and the inter-peak latencies of wave I-wave III, wave III-wave V and wave I-wave V at 80 dB nHL, and repetition rate of 11.1. The results showed that there was no significant correlation ($p<0.05$) between the two parameters at the three SNR conditions. The same is displayed in Table 4.21.

Table 4.21

Results of Spearman's rank-order correlation and significance values for SPIN scores and Inter peak latency differences at 80 dB nHL for 11.1 repetition rate

IPL/ SNR		I-III	III-V	I-V
0 dBSNR	r_s values	-0.14	0.22	0.1
	p values	0.288	0.098	0.439
-3 dBSNR	r_s values	-0.06	-0.03	-0.04
	p values	0.657	0.841	0.760
-5 dBSNR	r_s values	0.13	0.03	0.06
	p values	0.333	0.830	0.653

The literature review revealed no prior studies conducted to explore the relationship between speech perception in noise and the inter peak latencies for click evoked ABR. The results above show no correlation between the two parameters. The inter peak latencies were measured at a higher intensity (80 dB nHL) and a lower repetition rate (11.1/sec). At this intensity, a larger population of neurons would be active and since the repetition rate is low, neural synchrony would be maximum (Don et al.,1977; Chiappa et al.,1979 and Stockard et al.,1979) and variation across individuals in synchrony is less as compared to at higher repetition rate. This can be supported by the fact that there is no significant effect of the repetition rate on latency of wave V upto 50/sec (Paludetti, Maurizi, & Ottaviani, 1983). This condition does not tax the auditory system to evaluate the neural synchrony required to perceive speech in adverse listening conditions like in noise. Hence, no correlation could be seen between SPIN scores at different SNRs and inter peak latencies of click evoked ABR.

Chapter 5

Summary and Conclusion

Communication in everyday situation involves listening in adverse conditions like in presence of noise or reverberation. Precise temporal resolution is essential for speech perception in noise (Dubno, Dirks & Morgan ,1984; Gor´don-Salant & Fitzgibbons, 1993; Snell & Frisina, 2000). Several individuals with normal hearing sensitivity also complain of difficulty in communication in noise and reverberation. Clinically, diagnosis is based on the pure tone audiometry, and speech perception in noise is not affected by audibility (Summers et al., 2013 and Helfer & Vargo, 2009). Hence, to understand the communication difficulties faced by these individuals, the underlying mechanism of processing speech at different levels in the auditory pathway, in adverse listening conditions has to explored. Also, the utilization of temporal resolution skills for speech perception is highly variable across individuals (Kidd, Watson & Gygi, 2007). The present study was taken up to explore these variations in temporal resolution in individuals with normal hearing sensitivity and its utilization for perception of speech in noise. Also, there is little understanding of neurophysiological mechanism working towards the speech perception in noise. Hence, in our study, temporal resolution skills were assessed using behavioural and electrophysiological measures at the level of brainstem. The results of temporal resolution and temporal parameters of ABR were correlated to the scores of speech perception in noise using PB words.

A total of 60 ears of 30 native Kannada speaking adults in the age range of 18-25 years were considered for the present study. It was made sure through a detailed case history that none of the participants were exposed to long durations of noise, music or subjected to prolonged medication for associated problems. They also had no history or presence of neurological and otological disorders. To rule out the presence of any peripheral abnormality, a audiological test battery consisting of pure tone audiometry, speech audiometry, immittance measurements, transient evoked otoacoustic emissions was carried out.

The speech perception in noise was assessed using PB words in Kannada. The noise used was speech shaped noise mixed with the PB words at three different SNRs of 0, -3 and -5 dB SNR.

To assess the temporal resolution abilities, a behavioural measure of Across Channel Gap Detection Test (AC GDT) using one NBN centered at 1000 Hz and another NBN centered at 2000 Hz, with the former being the lead marker and latter being the lag marker, was conducted on all the participants using Psycon v2.18 experimental software. AC GDT was established using a three alternate forced choice method.

Electrophysiological measure of temporal processing was assessed using Auditory Brainstem Response (ABR) which was elicited using clicks at intensities of 80, 60, 50 and 40 dB nHL. At the intensities of 80 and 60 dB nHL ABR was evoked at repetition rates of 11.1, 30.1, 70.1 and 90.1/sec, and at intensities of 50 and 40 dB nHL for repetition rate of 30.1/sec. The parameters considered were latency of wave I and wave V across repetition rates and intensities, latency intensity function of wave V, duration of wave V, slope of wave V and inter peak latency.

The above parameters of different tests were analysed using inferential statistics and correlation between the SPIN scores and the temporal resolution measure of AC GDT and temporal aspects of ABR was carried out.

- The SPIN scores decreased with the decrease in SNR. This is due to the reduction in the modulations of the temporal waveform due to the masking by the noise leading to reduced ‘listening in dips’ and hence leads to poorer scores.
- AC GDT values procured in the present study was similar to previous studies studying AC GDT, and was higher than WC GDT values reported in literature. This could be due to the processing of lead and lag marker of AC GDT in two separate neural channels.
- There was a significant increase in the latency of wave I at 80 dB nHL and wave V at 80 and 60 dB nHL with the increase in the repetition rate, this may be due to the adaptation of neurons leading to reduced neural activity and synchrony at the level of brainstem.
- Latency of wave V decreased significantly with the decrease in intensity. This could be due to the participation of high and low spontaneous rate fibres at the higher intensities, and activation of only high spontaneous rate fibres at lower intensities. There is also a shift in cochlea from a passive to an active system at higher intensities.
- The duration of wave V increased significantly with the increase in repetition rate at 80 dB nHL, this may also be due to the effects of adaptation of auditory neurons leading to reduced neural activity and decreased synchrony leading to prolongation of wave III and wave V.

- The slope of wave V decreased with the increase in repetition rate. Due to the effects of adaptation, the latency of peak and trough of wave V increases and the amplitude of wave V decreases with the increase in repetition rate.
- A significant negative correlation was present between AC GDT and SPIN scores at -5 dB SNR, indicating that the temporal resolution abilities of an individual could predict speech perception in noise.
- The parameters of slope of wave V at 80 dB nHL for repetition rates of 11.1, 30.1 and 70.1/sec correlated positively with SPIN scores at 0 dB SNR; and at 60 dB nHL for repetition rate of 70.1/sec with SPIN scores at -3 and -5 dB SNR, showing that the slope of wave V is a sensitive measure to predict the scores of SPIN.

Conclusion

Thus this study emphasizes that AC GDT can be used as a tool to assess perception in noise. ABR can be used as an objective measure to evaluate the ability of individuals to perceive speech in noise. However, not all of the temporal parameters of ABR are sensitive enough to provide this information. Also, the individual variability for the utilization of the temporal resolution skills may be due to the differences in the neural coding at the level of brainstem.

Future directions

1. In the present study, ABR was elicited using clicks as a stimulus. Further research can be done with the use of speech as a stimulus and compare across different intensities and repetition rates.
2. The temporal resolution skills can also be assessed using speech, like using the just noticeable differences of a voiced-voiceless continuum and then comparing the same with electrophysiological measures which can give a better understanding of the mechanism of processing speech.

Implications

The outcomes of the present study imply that:

1. AC GDT can be used as a predictor for SPIN especially in individuals with normal hearing sensitivity. AC GDT can be used for diagnostic purpose and also can be a measure for efficacy of therapy.
2. ABR may be used to predict speech perception in noise in the pediatric population.
3. The present study has shown the neurophysiological activity at the level of brainstem and its relation to speech perception in noise in individuals with normal hearing sensitivity.
4. The study gives a better understanding of the relationship between speech perception in noise, temporal processing and the neural activity at the level of brainstem.
5. This study can add on to the already existing literature.

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