

Neuro-Physiological Mechanisms of Speech Perception in Noise

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Abstract

The study investigated the relative importance of different physiological measures of top-down modulation for speech perception in noise. Two of the physiological measures; contralateral suppression of OAEs mediated by MOCB and context dependent encoding of AEPs (ABR & ALLR) mediated by corticofugal pathway were assessed. These measures were recorded and analyzed in two groups of participants, one with good and the other with poorer speech perception in noise. Young and elderly individuals were considered for the two groups assuming that the elderly individuals would have relatively poorer speech perception in noise. Overall, the findings of the study indicated that both MOCB and corticofugal functioning do have regulatory roles in speech perception in noise, although the two physiological measures did not correlate with each other. The MOCB showed greater regulatory influence compared to corticofugal functioning.

Chapter 1

Introduction

Perception of speech in degraded listening situations has eluded hearing scientists since long (Jones & Rosen, 1993; Gordon-Salant & Fitzgibbons, 1993; Gordon-Salant, 1995; Wiley et al., 1998; Killion & Niquette, 2000; Souza et al., 2007; Hargus & Kim et al., 2006). Accurate perception of speech involves the precise encoding of its acoustic parameters, which becomes challenging for the auditory system in the presence of noise (Cooper & Cutts, 1971; Jones & Rosen, 1993). This process of perceiving speech in the presence of noise is called the Auditory Figure-Ground in psychoacoustic terms, wherein figure refers to speech and noise refers to Ground (Teki, Chait, Kumar, von Kriegstein, & Griffiths, 2011).

The auditory figure-ground perception is a complex phenomenon and is inevitable as one is faced with numerous instances of listening in the presence of noise in daily listening situations. The noise impedes normal speech perception and is likely to result in a communication breakdown. However, this is not an issue of concern for most normal hearing individuals as normal auditory system has mechanisms that counter the effects of noise on speech perception.

The perception of speech in noise has been reported to be abnormal in auditory based disorders (Gordon-Salant, 1985; Festen & Plomp, 1990; Rance et al., 2004). Poor speech in noise perception is seen in individuals with varying degrees of cochlear and retrocochlear hearing loss (Plomp, 1978; Killion & Niquette 2000; Rance, 2005; Souza, Boike & Witherell, 2007) as well as in individuals with normal hearing sensitivity such as (C)APD (ASHA CAPD Task Force, 1996), some individuals with ANSD auditory neuropathy spectrum disorder (ANSD) (Starr et al., 1996; Rance, 2005; Zeng, Kong, Michalewski & Starr, 2005), language-based disorders (Chandrasekaran et al., 2009; Hornickel et al., 2009; Hornickel & Kraus, 2013), cognitive difficulties (Russo et al., 2009) and advancing age (Dubno, Dirks & Morgan, 1984; Studebaker et al., 1997). The difficulties reported in these individuals have been attributed to various processing deficits. For example, Moore (2010) reported alterations in the frequency resolution, excitation patterns, pitch and temporal coding as underlying mechanisms of disrupted speech in noise perception in cochlear hearing loss. The findings is true in in different

degrees of hearing loss (Moore & Glasberg, 1993) Similarly, the severely impaired speech perception in noise in individuals with ANSD has been attributed to poor gap detection thresholds and temporal modulation transfer function (Rance, 2005; Zeng et al., 2005). Hence, it may be inferred that the temporal processing among others is very important in the perception of speech in noise.

In addition to peripheral lesions, poor speech perception in noise has been reported in individuals with hearing sensitivity within normal limits, like in those with dyslexia and (C)APD. The underperformance in these individuals is attributed to deficits in phonological decoding and pitch encoding which impede the separation of speech and noise in the on-going sound stream (Sperling, Lu, Mannis & Seidenberg, 2005; Ahissar, Lubin, Putter-Katz & Banai, 2006; Ziegler, Pech-George, George & Lorenzi, 2009), in other words deficits in auditory figure-ground. Additionally, most individuals with dyslexia have been known to have auditory closure deficits (Tallal, Miller & Fitch, 1999) which have been found to be correlated with both bottom-up and top-down physiological mechanisms (Kumar & Vanaja, 2004; Chandrasekaran & Kraus, 2009).

1.1 Bottom up Regulation of Speech Perception in Noise

Both cochlear and neural mechanisms are vital for bottom up regulation of speech perception in noise. **At the cochlear level** compressive non-linearity, frequency selectivity and temporal fine structure processing are important mechanisms that aid in speech perception in noise. Hopkins and Moore (2007) reported that processing of temporal fine-structure information is impaired in individuals with mild to moderate degrees hearing loss. They reported that processing of temporal fine structure is important in the extraction of speech from fluctuating noise. According to them, compressive non-linearity and frequency selectivity are very important processes, which help in extracting the temporal fine structure cues at the cochlear level to facilitate release from masking. Altered frequency resolution also reduces the spectral contrasts in speech signal and makes it difficult to differentiate speech and noise (Preminger & Wiley, 1985; Thibodeau & Van Tasell, 1987; Turner & Henn, 1989; Moore, 1995).

Poor speech perception in noise can also be associated with **disruption of the afferent neural input** in spite of cochlear processing being normal. In individuals with

normal hearing sensitivity, Hornickel et al. (2009) showed that the sub-cortical encoding of the timing difference in speech sounds correlated with speech perception in noise. They suggested that the pre-conscious sub-cortical encoding of timing information at the brainstem is very important for speech perception. They suggested that the sub-cortical centres differentiate the speech sounds from each other and this information is later processed and perceived at the cortical level. They found that individuals who had poor sub-cortical differentiation of speech sounds had poorer speech in noise perception, while individuals with good sub-cortical differentiation of the speech sounds had better speech in noise perception.

Similarly, Anderson et al. (2011) found poor speech in noise perception in individuals with above 60 years of age. The individual had normal hearing sensitivity and cognitive functioning. They also found poor brainstem encoding of pitch in the presence of noise in the older individuals. This result is in agreement with several other studies (Hornickel et al., 2012; Wible, Nicol & Kraus, 2002; Anderson & Kraus, 2010; Bidelman & Krishnan, 2010). These authors pointed out that sub-cortical encoding of pitch involves accurate coding of timing information in speech. They also reported that any disruption in the coding of timing information by afferent neurons at the brainstem impairs the ability to extract the desired speech signal from the background noise based on pitch information.

Subtle deficits in the auditory processing are expected consequent to **age related changes in the auditory neural pathway**. Elderly individuals have been reported to have difficulty perceiving speech in degraded listening situations in spite of normal pure tone thresholds (Dubno, Dirks & Morgan, 1984; Hargus & Gordon-Salant, 1995; Kim et al., 2006). Dubno et al. (1984) found that normal hearing older adults of age 65 years and above, had significantly poor speech perception in noise.

Hargus and Gordon-Salant (1995) reported that the Speech Intelligibility Index underestimated the speech in noise perception in mild hearing loss. These results suggest that the poor speech perception in noise is not solely from reduced hearing sensitivity, rather a higher-level auditory processing deficit. Pichora-Fuller (2003) suggested that there are other processes like supra-threshold temporal processing and cognitive abilities, which affect the speech perception in noise.

The brainstem is vital in the encoding of timing information of speech signals. The F0 and the harmonics are precisely encoded in the auditory brainstem and hence, are very important for speech perception in noise (Galbraith et al., 1995). The speech evoked auditory brainstem response (ABR) is primarily generated from the inferior colliculus in the mid-brain (Smith, Marsh, & Brown, 1975).

The speech evoked ABR is widely used in the assessment of the neural encoding of timing information in speech. The speech ABR is sensitive to the slightest deficits in temporal processing. The speech ABR mimics the F0 and harmonic information of the stimulus and helps in the direct comparison of the stimulus with the response. Likewise, it precisely encodes every portion of the speech sound like burst, transitions, voice-onset-times and cycle-to-cycle periodicity. This helps in assessing the fidelity of the brainstem with extreme precision (Chandrasekaran & Kraus, 2010).

Individuals with speech in noise perception deficits have been shown to be having poor brainstem encoding for pitch and harmonics of speech (Cunningham et al., 2001; Russo et al., 2009). Individuals with learning disability (Song, Banai, & Kraus, 2008; Banai, Abrams, & Kraus, 2007), phonological disorders (Goncalves et al., 2011;), aging (Anderson et al., 2012,2013) have been shown to be having poor encoding of timing features in speech ABR. The Speech ABR has also shown good correlation with the speech perception in noise scores in the above studies. These constitute a bottom up processing insufficiency in individuals with such deficits.

1.2 Top Down Modulations of Auditory system

The top-down modulation is believed to be mediated by different neural networks such as cortical facilitatory (Grill-Spector, Henson, & Martin, 2006; James & Gauthier, 2006), the corticofugal (Zhang & Suga, 1997; Gao & Suga, 1998; Yan & Suga, 1998; Suga, Xiao, Ma & Ji, 2002) and the olivocochlear bundle (Giraud, Collet, Chery-Croze, Magnan & Chays, 1995; Veuille, Collet & Duclaux, 1991).

The olivo-cochlear bundle (OCB) extends from the Superior olivary complex to the outer hair cells and the afferent first order neurons. Rasmussen (1946) was the first to describe the course of OCB. Later, Guinan and his colleagues (Warr & Guinan, 1979; Guinan, Warr & Norris, 1983) showed that there are two groups of fibers in the OCB: Lateral and medial OCB. *Lateral olivocochlear bundle* originates in the lateral superior

olivocochlear nucleus and innervates the afferent fibers of the ipsilateral inner hair cells while the *Medial olivocochlear bundle*(MOCB) originates in the medial superior olivary nucleus and terminates on the contralateral outer hair cells. Together, both the olivocochlear bundles modulate the functioning of the afferent nerve fibers and the outer hair cells and influence the afferent sound transmission (Galambos, 1956). Figure 1.1 shows the course of lateral and medial OCBs.

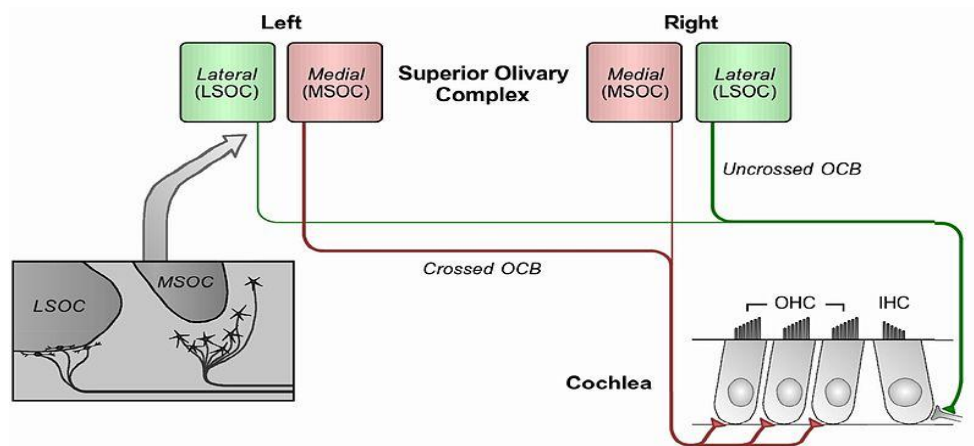


Figure 1.1: An illustration of the Medial efferent system. Retrieved from http://en.wikipedia.org/wiki/Olivocochlear_system on 27.10.2013.

Galambos (1956) through electrical stimulation of the MOCB found that the role of the MOCB is mainly inhibitory and it suppresses the compound action potential. This change in the compound action potential is attributed to the altered micromechanical properties of the outer hair cells secondary to MOC stimulation, which in turn affect the inner hair cell receptor potential (Brown & Nuttall, 1984; Brown, Nuttall, & Masta, 1983).

On the other hand, MOCB is not only activated by electrical stimulation, but also contralateral acoustic stimulation (Collet et al., 1990; Berlin et al., 1993, 1994; Harrison & Burns, 1993; Kujawa et al., 1993; Chery-Croze, Moulin, & Collet, 1993; Hood et al., 1996). The functioning of the MOCB is not only seen as a reduction in compound action potential, but also is seen as a reduction in otoacoustic emission amplitude (Collet et al., 1990; Hood et al., 1996).

The measurement of efferent system functioning using contralateral acoustic stimulation is also called Contralateral Suppression of Otoacoustic Emissions (CSOAE)

(Berlin et al., 1994). The contralateral acoustic stimulation leads to MOCB mediated alteration in the mechanical properties of the outer hair cells leading to a reduction in OAE magnitude. The CSOAE has been measured for the different types of OAE like transient OAE, (Berlin et al., 1994; Collett et al., 1992), distortion product OAE (Chery-Croze, Moulin, & Collet, 1993; Kumar, Methi, & Avinash, 2013), spontaneous OAE (Harrison & Burns, 1993; Mott et al., 1989) and stimulus frequency OAE (Guinan et al., 2003).

Individuals with deficits in speech in noise perception have been shown to have lesser CSOAE magnitudes than those without such deficits (Kumar & Vanaja, 2004; deBoer & Thornton, 2008). Children and adults with dyslexia often have speech perception deficits especially in noise (Ziegler et al., 2009; Dole, Hoen, & Meunier, 2012). Kumar and Vanaja (2004) found that the poor speech perception in individuals with dyslexia was associated with reduced CSOAE magnitude.

Elderly individuals with normal hearing sensitivity show speech perception deficits in the presence of noise as discussed earlier. Numerous studies have shown that CSOAE magnitude is reduced in older individuals (Kim et al., 2002). Mukari and Mammat (2008) found that individuals older than 50 years had reduced CSOAE magnitude and poor speech in noise perception than their younger counterparts.

This relationship between the CSOAE and speech in noise perception is attributed to the anti-masking effect of the MOCB (Kawase & Liberman, 1993; Kawase, Delgutte & Liberman, 1993). The anti-masking effect suggests that the MOCB preferentially suppresses the background noise and enhances the regularly occurring/varying speech input, thus, improving speech in noise perception. The MOCB modulates the afferent neural input to improve perception.

More recently, the role of cortico-fugal pathway in speech perception in noise has been explored. The cortico-fugal pathway was evaluated using a novel paradigm to record speech ABR (Chandrasekaran & Kraus, 2009). This paradigm involved recording of speech ABR to a target syllable in the context of various other syllables and comparing it with another recording to the same target syllable without the contextual syllables. The former was called the variable/contextual paradigm, and the latter, repetitive paradigm. Although this paradigm was common in the recording of auditory

long latency responses, it was used as a maiden technique in the recording of speech ABR by Chandrasekaran and Kraus (2009).

Chandrasekaran and Kraus recorded ABR to a syllable /da/ in the context of seven other syllables (contextual paradigm) and compared it with the ABR recorded to a /da/ in the repetitive paradigm. They found that the ABR in the repetitive paradigm had higher spectral magnitudes in the H2, and H4 regions compared to the ABR in the contextual paradigm. They also found that this contextual effect was absent in individuals with dyslexia. Additionally, this contextual effect was found to be correlating with speech in noise perception scores i.e. greater the contextual effect, better was the speech in noise perception. Parbery-Clark et al. (2011) also used the same paradigm to compare musicians vs. non-musicians. They found that this contextual effect was more pronounced in musicians than non-musicians, and it again correlated with speech in noise perception scores. Strait, Hornickel and Kraus (2011) used the same paradigm and found that the enhancement of H2 and H4 spectral magnitudes of ABR in the repetitive paradigm compared to the contextual correlated with the music aptitude and reading scores in children.

The selective enhancement of the encoding of speech ABR in the repetitive paradigm as compared to the contextual paradigm has been attributed to functioning of the cortico-fugal pathway (Chandrasekaran & Kraus, 2011; Parbery Clark et al., 2011). The repetitive paradigm has a regularly occurring/repeating stimulus which the auditory system predicts. This results in a more fine-tuned and better encoding of the target stimulus at the brainstem. In the contextual paradigm the target syllable is unpredictable and is not regularly varying, thus the auditory system cannot predict the on-going signal and thus, does not fine-tune the brainstem encoding of the sound. This function of regularity detection and fine-tuning of the brainstem encoding is attributed to the function of the corticofugal pathway.

The corticofugal pathway or the back projection pathway was first described by Zhang and his colleagues in two seminal papers on auditory processing in bats. Zhang, Suga and Yan (1997) selectively inactivated a few frequency specific cortical neurons of a bat. As a resultant, they observed that the responses of best-frequency matched collicular and thalamic nucleus was reduced. It was also found that the frequency

response of the other neurons changed and matched that of the inactivated cortical neurons. Zhang and Suga (1997) extended the above study and found similar results and proposed that the corticofugal pathway provides a positive feedback to the thalamic and the collicular nuclei to preferentially fine tune the afferent input to the cortex. In the same lines as the above studies, Suga et al. (2002) also found evidence of corticofugal modulation, but in a different paradigm. They found that when a sound was repetitively presented along with an external electrical stimulus to the leg, the frequency response of the collicular neurons were altered. They concluded that the brain looks at moment to moment changes in the sensory stimulation and selectively facilitates or inhibits the responses of the sub-cortical neurons. This constitutes the top-down mechanism of auditory processing.

Thus, the contextual effect as described in Chandrasekaran and Kraus (2009), Parbery-Clark et al. (2011) and, Strait et al. (2011) can be considered as a non-invasive index of top-down processing mediated by the corticofugal pathway. Corticofugal pathway can be considered an online statistical analyser. It analyses the moment-to-moment changes in the afferent input and selectively enhances the responses to the regularly occurring signal. Context-dependent speech ABR can be considered as an index of top down modulation and regularity-detection of the afferent input at the sub-cortical neurons. This contextual effect in ABR has been shown to be correlated with superior auditory perceptual abilities like better speech perception in noise and musical abilities.

Context-Dependent Encoding of the Auditory Long Latency Responses

The auditory long latency responses (ALLR) are index of sound processing at the cortical neurons, namely the thalamo-cortical pathway primary and secondary auditory cortices, and the association cortices (Woods et al., 1987; Crowley & Colrain, 2004). These are obligatory cortical responses and are evoked by various kinds of stimuli like tones, clicks and speech. The ALLRs are widely used as a non-invasive tool for cortical auditory processing.

The ALLRs are affected greatly by the stimulus context. Recording of ALLR in an oddball paradigm with passive attention produces an additional negativity to the infrequently presented sound in the 100 to 250 ms region. This is also called the

mismatch negativity (MMN) (Naatanen, 1995; Naatanen, Jacobsen, & Winkler, 2005). The same paradigm with the inclusion of active attention, produces a late positivity in the 250-600 ms region and is called the P300 (Ruchkin, Sutton, & Stega, 1980; Polich, 2007). The changes in stimulus types, context and attentional factors bring about a great change in the ALLRs. This sensitivity to changes in stimulus context has been extensively used in recording of ALLR.

Stimulus repetition has a drastic effect on the ALLR. Crowley and Colrain (2004) observed the N1 amplitudes in blocks throughout the recording. They reported decrease in N1 amplitude as the recording progressed.

Boutros et al. (2011) recorded LLR in an S1-S2 repetition suppression paradigm. The S1 and S2 were identical clicks with an interval of 500 ms, while each pair of S1-S2 were spaced 8 seconds apart. The N1 to the S2 was lesser in amplitude than the N1 to S1. They suggest that the S1 acts as an initial registration activity in the pyramidal neurons and also activates the inhibitory inter-neurons which suppress the pyramidal response to N1. Earlier, it was thought that this suppression of N1 amplitude was due to neural refractoriness. Sable et al. (2004) and Mouraux and Iannetti (2008) showed that this repetition related suppression of N1 amplitude is related to the 'Novelty' aspect of the stimulus. If the stimulus is novel, then there is no suppression of N1.

Friston (2005) put forth a 'predictive coding model' to explain repetition suppression. In this study it was suggested that there are forward and backward projections in the auditory system. The forward projections carry the afferent input i.e., they move from the lower to the higher centres. The backward projections carry information from the higher to the lower centres. Friston proposed that, the backward projections continuously predict the next stimulus based on the predictions of the higher centres in the nervous system and selectively inhibit or facilitate the encoding in the lower centres of the brain (the thalamocortical pathway and the Heschl's gyrus). Costa-Faidella et al. (2011) showed that this repetition related suppression is related to the predictability of the stimulus. The more predictable/regular the stimulus, greater is the suppression. They also suggested that this repetition related suppression is mediated by the association cortices in the planum temporale, which suppress the activity in the primary auditory cortex.

The regularity of the stimulus is considered the main feature in repetition related suppression in the ALLRs. Deviance from regularity results in release from this suppression and better ALLR amplitudes. This repetition related suppression can also be considered a mechanism of regularity extraction cortical centres in the auditory system, where, regularly occurring stimuli are coded as reduced ALLRs and irregularly occurring stimuli are coded as increased ALLRs.

The repetition related suppression of ALLRs is considered an important aspect auditory perception. However, studies have not investigated the role of this mechanism in speech perception-in-noise. The role of this mechanism in auditory perception is still a grey area. Figure 1.2 illustrates the different top-down pathways in the auditory neural system.

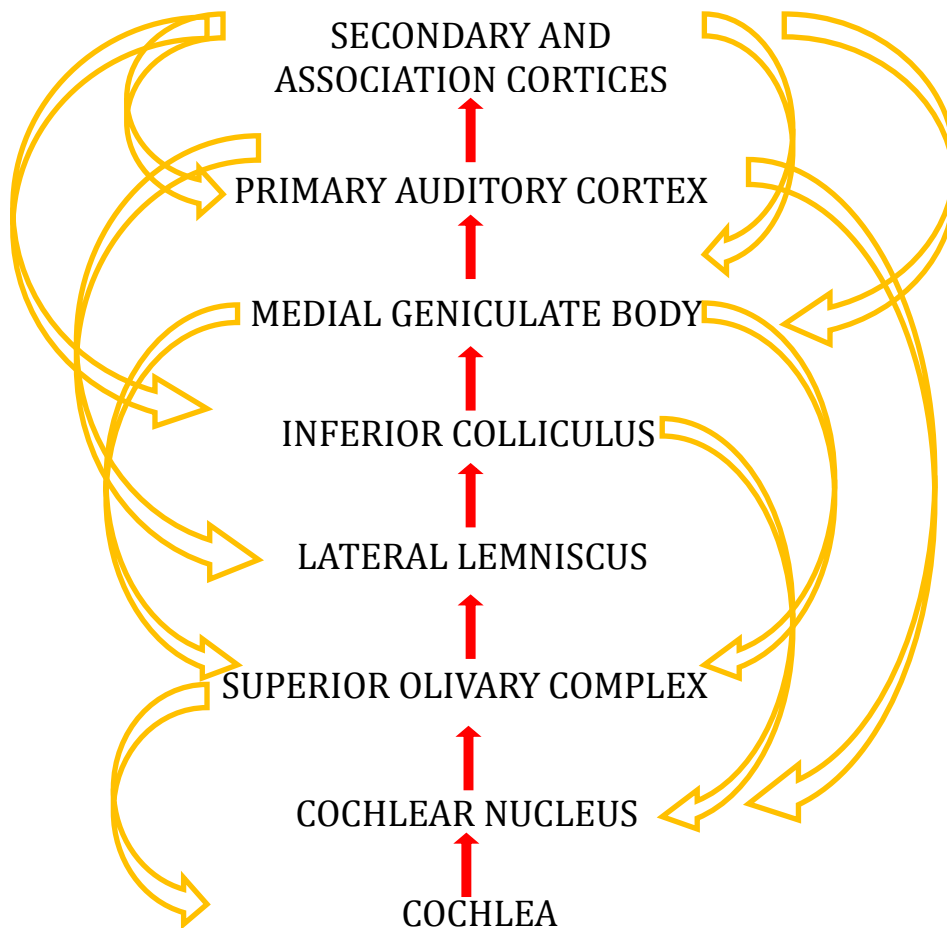


Figure 1.2: Illustration of the top down projections in the auditory neural pathway

1.3 Justification for the study

The corticofugal branches (Yan & Suga, 1998; Suga, Xiao, Ma & Ji, 2002) and the medial olivocochlear pathway (Kawase, Delgutte, & Libermann, 1993; Kumar & Vanaja, 2004) share a common objective of fine tuning the neural responses for better perception. However, it is not clear if these two mechanisms function as separate entities or they work in unison and are part of a the same neural network. Given, the proximity and the numerous connections between the Inferior colliculus and the MOC, it would be palpable to assume both as a part of the same regularity detection mechanism in the sound-neural statistics by top-down control. However, it would be erroneous to consider so, without experimental validation.

Literature, has shown that top down modulation is important for speech perception (Chandrasekaran et al., 2009; Kumar et al., 2010). The relative contribution of the top-down mechanisms can be well delineated when studied in individuals with good and poor speech perception in noise in spite of the normal peripheral hearing sensitivity. It has been widely reported that aged individuals have difficulty perceiving speech in the presence of noise in spite of normal peripheral hearing sensitivity (Crandell, Hensch & Dunkerson, 1991; Anderson et al., 2011 among others). Examining the modulatory mechanisms and speech in noise perception in young and aged individuals with normal hearing sensitivity would help us in understanding these mechanisms better. We hypothesized that reduced malleability of the auditory system in elderly hearing individuals may be one of the factors responsible for poor speech understanding in adverse listening conditions in this population. Understanding the relationship between the adaptive auditory system and perception of speech in noise is clinically relevant. Hence, in the present project it was proposed to explore the relationship between context dependent speech evoked auditory brainstem responses, contralateral suppression of otoacoustic emissions and speech in noise.

Furthermore, the aforementioned two top-down mechanisms have been shown to be related to speech in noise perception. However, there aren't any studies which have focussed on the relative contribution of these top-down mechanisms to speech in noise perception. A probe in this direction would help us understand these mechanisms, and their contributions to speech perception in noise, without which the distinction if

any, in these mechanisms would remain clouded. It would also be valuable in making clinically relevant decisions in deciding assessment tools.

The present study thus, investigated the null hypothesis – 'perception of speech in noise and auditory-physiological measures of online modulation and regularity detection at the cortical and sub-cortical level are not different in young and elderly listeners'.

1.4 Statement of the Problem

The present study was focussed on exploring the inter-relationship among the different top-down mechanisms aiding in the perception of speech in noise as there is no such literature to the best of the authors' knowledge exploring the same. The context dependent speech evoked ABR in young adults and aged individuals would help us understand the cortico-fugal mechanisms and brainstem encoding in ears with good and poor speech in noise perception. The analysis of the contralateral suppression of otoacoustic emissions in the two groups would aid in understanding the MOCB and its relation with context dependent brainstem encoding and speech in noise perception. Also, context dependent cortical auditory responses would throw more light on the cortical encoding of regularity and if it is translated as cortico-fugal modulation.

1.5 Objectives of the Study

1. To compare the the context dependent speech evoked auditory brainstem responses, context dependent speech evoked auditory late latency responses, efferent suppression of otoacoustic emission and speech identification in noise between adults and elderly individuals with normal hearing
2. To assess the inter-relationship among context dependent speech evoked auditory brainstem responses, context dependent speech evoked auditory late latency responses, efferent suppression of otoacoustic emission and speech identification in noise.

Chapter 2

METHOD

The following method was adopted to investigate the relationship between speech in noise perception and a few of the neurophysiological mechanisms that reflect the top-down modulations in the auditory system. The specific neurophysiological mechanisms analysed in this study were (a) subcortical and cortical encoding of speech, analysed using the speech evoked brainstem and cortical auditory evoked potentials respectively, (b) measures of regularity detection, analysed using the context dependent speech evoked brainstem and cortical responses (b) Medial olivocochlear functioning, analysed using the contralateral suppression of click evoked otoacoustic emissions.

2.1 Participants

A total of 60 individuals participated in the present study. All the individuals resided in and around Mysore district in Karnataka and were fluent speakers of the Kannada language. They had a minimum educational qualification of tenth grade. Based on their age, the participants were assigned to either 'elder' or 'younger' group. The elder group consisted of 30 elderly individuals in the age range of 50 to 65 years, while the younger group consisted of 30 individuals in the age range of 18 to 30 years. A total of 74 individuals were evaluated and 60 who met the following participant inclusion criteria were selected:

- Hearing thresholds lesser than 15 dBHL at octave frequencies between 250 Hz and 4000 Hz
- Presence of acoustic middle ear reflexes at sensation levels of 70 to 85 dB (ref: Pure tone hearing thresholds) (Gelfand, 1990)
- Presence of transient click evoked otoacoustic emissions (TEOAEs) with an overall Signal to Noise Ratio of 6 dB SPL and reproducibility of >70% (Hurley & Musiek, 1994)
- No history of otological/audiological or neurological disorders

Written consent was obtained from all the participants before inclusion into the study. The data from each participant was collected in two phases. The first phase involved obtaining the physiological measures of top-down modulation, namely context dependent brainstem and cortical responses and contralateral suppression of click evoked otoacoustic emissions. The second phase involved obtaining the behavioral measure i.e., the signal to noise ratio at which the participant perceives 50% of the speech correctly.

2.2 Behavioural Measure

The speech stimuli were taken from the QuickSIN-Kannada test developed by Methi, Avinash, and Kumar (2008). The sentences were spoken by an adult male who was a native speaker of Kannada. Sentences were digitally recorded in an acoustically treated room, on a data acquisition system using a 44.1 kHz sampling frequency and 16-bit analog to digital converter. Multi talker (Eight talkers) babble was used as the background noise.

SNR-50 for Kannada sentences were evaluated for all the participants using QuickSIN-Kannada (Methi, Avinash & Kumar, 2008). The Quick SIN-Kannada test has seven equivalent lists of seven sentences each. The sentences were presented at SNRs of +20 dB to -10 dB in steps of 5 dB. These sentences were presented through circumaural Sennheiser HDA200 headphones driven by a standard sound card of an Acer 4830T notebook PC at an intensity of 40 dB HL. Only the left ear of each participant was tested. Only the List 2 of QuickSIN-K was used in the study, to avoid any extraneous effect of list differences on the SNR-50. The total number of words repeated correctly by each participant was noted down and the SNR-50 was calculated using the Spearman-Kärber metric (Finney, 1952; Tillman & Olsen, 1973) for the QuickSIN-K:

$$\text{SNR 50} = 22.5 - \text{total number of words correct.}$$

2.3 Physiological Measures

2.3.1 Auditory Evoked Potentials

Test Stimuli

Consonant-vowel (CV) syllables /bi/, /bu/, /gi/ and /da/ were chosen for recording speech evoked Auditory Evoked Potentials. The syllable /da/ was the stimulus of interest, while the others served only as the contextual stimuli. The contextual stimuli were chosen such that they differed from the /da/ syllable in terms of the vowel, stop burst and the second formant transition (place of articulation).

The stimulus recording was done in an acoustically treated room. The chosen CV syllables were uttered by an adult male who was a native speaker of Kannada. The utterances were recorded using a dynamic microphone placed at a distance of six inches from the speaker's mouth. The microphone output was routed to the Stim² hardware (Compumedics-Neuroscan, Charlotte, NC, USA) and recorded with a resolution of 16 bits at a sampling rate of 44100 Hz in the Sound module of the Stim² software suite.

The recorded syllables were initially analysed using Speech Processing and Synthesis toolboxes (Childers, 2000) incorporating a Linear predictive coding (LPC) algorithm. This was done in order to extract and modify the different acoustic parameters independently. The modified LPC parameters were used to synthesize the CV stimuli of duration of 100ms using the toolboxes. These synthetic speech syllables /ba/, /bu/, /gi/ and /da/ were subjected to a perceptual rating for naturalness and quality from 10 sophisticated listeners with normal hearing. Based on the ratings of the listeners, modifications were done in the LPC parameters to resynthesize the stimuli with higher naturalness. The waveforms and spectrograms of the four stimuli are shown in Figure 2.1. Table 2.1 gives acoustic parameters of the primary and contextual stimuli synthesized in the study.

Table 2.1: Acoustical parameters of the primary and contextual stimuli synthesized for the study

Stimulus	Type of change from /da/ syllable	F0 In Hz	F1 In Hz	F2 In Hz	F3 In Hz	F4 In Hz	F5 In Hz
/da/	Primary syllable	100	563 to 692	1453 to 1281	2510 to 2475	3285 to 3287	Steady 3472
/ba/	Place of articulation	100	563 to 630	1168 to 1193	2488 to 2566	3690 to 3748	Steady 5091
/bu/	Place of articulation and vowel	117	324 to 328	836 to 845	2533 to 2534	3667 to 3746	Steady 5351
/gi/	Place of articulation and vowel	113	267 to 295	2213 to 2377	3042 to 3147	4049 to 4015	Steady 4846

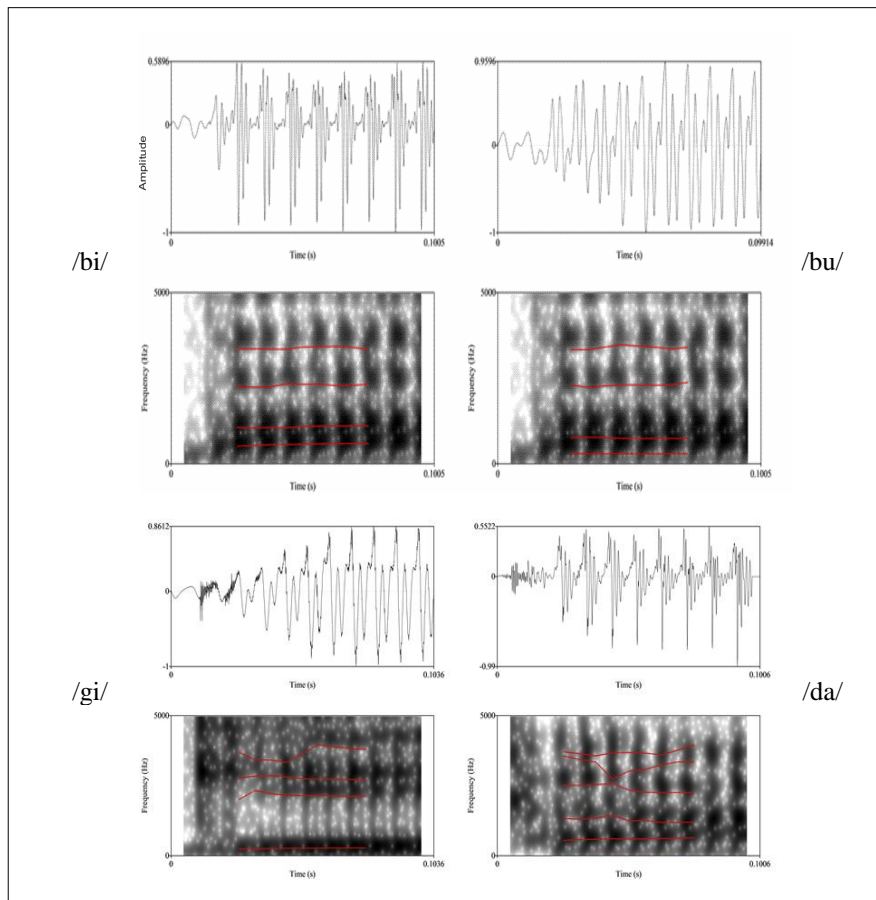


Figure 2.1: The waveforms and spectrograms of the 4 synthetic stimuli generated in the study (Top left: /bi/, Top right: /bu/, Bottom left: /gi/, Bottom right: /da/).

Recording of AEPs

The participants were made to sit in a reclining chair and ensured for their comfort. During the course of the experiment, the participants were shown a captioned movie of their choice. This was done to maintain a passive yet wakeful state. Brainstem responses were recorded in two different paradigms; one repetitive paradigm and the other variable paradigm. The repetitive paradigm involved the presentation of the /da/ stimulus repetitively in the conventional paradigm. The variable paradigm involved the presentation of the /da/ stimulus in the context of the stimuli /ba/, /bu/ and /gi/. Each of the stimuli had a frequency of occurrence of 25% of the total stimulus presentations. The stimulus presentation was controlled in the Gentask module of the Stim² system (Compumedics-Neuroscan, Charlotte, NC, USA). The stimulus presentation sequence was prepared such that two /da/ syllables did not occur consecutively. A schematic representation of the two paradigms is depicted in Figure 2.2.

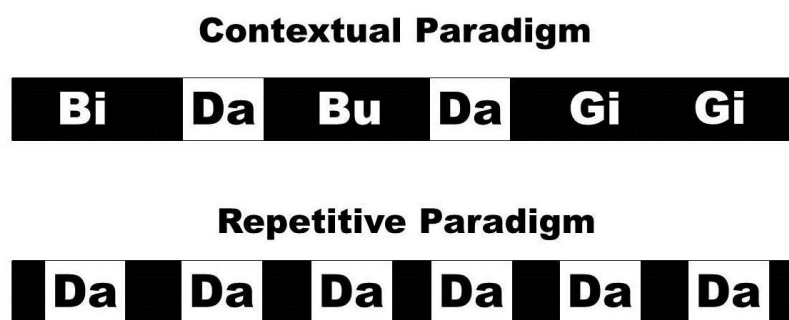


Figure 2.2: Schematic representation of the two paradigms used in the study. The upper panel represents the contextual paradigm and the lower panel represents the repetitive paradigm.

The scalp EEG responses were picked up using a 64 channel QuickCap™ (Compumedics-Neuroscan, Charlotte, NC, USA) with AgCl sintered electrodes. The electrode cap was adjusted to position the electrodes on the scalp according to the 10-10 EEG placement system (Chatrian, Lettich, & Nelson, 1985). Of the 64 electrodes in the cap, speech evoked ABR were recorded only from the Cz site, while speech evoked LLR was recorded from 7 electrode sites; Cz, Fz, Pz, C3, C4, T7 and T8. The raw EEG output of the electrode cap were recorded in the Acquire module of the Scan 4.4 suite (Compumedics-Neuroscan, Charlotte, NC, USA) interfaced by a Synamps²

preamplifier. The participants were shown a captioned movie with its volume turned down (less than 40dB HL) to maintain a passive yet wakeful state. The protocol used to record the ABR and ALLR is given in Table 2. The raw EEG responses were later analysed offline in the Edit 4.4 module.

Table 2: Stimulus and acquisition parameters used to elicit ABR and ALLR

Parameter	Settings in ABR	Settings in ALLR
Stimuli	Repetitive paradigm: /da/ (primary)	
	Variable paradigm: /bi/, /bu/ and /gi/ (context)	
Frequency of occurrence of /da/ stimulus	25% in the variable paradigm	
Ear	left ear	
Duration of stimuli	100 ms	
Intensity	70 dB nHL	
Inter-stimulus Interval (onset to onset)	166.67 ms	600 ms
Polarity	Alternating	
Total Number of sweeps per recording	6144	1344
Epoch	160 ms	600 ms
Electrode montage	Cz referenced to opposite ear mastoid	Cz, Fz, Pz, C3, C4, T7 and T8
Sampling frequency	20000 Hz	1000 Hz
Amplification	10 times	
Filter setting	Lowpass filtered to 3500 Hz using a DC filter	Lowpass filtered to 100 Hz using a DC filter
Artifact rejection threshold	+/-35 μ V (offline only)	+/-75 μ V (offline only)

Response Analysis

In the offline analysis of ABR, to begin with the raw EEGs were band-pass filtered using an FIR filter with a 80 Hz high pass cut off and a 1500 Hz low-pass cut off, each with a slope of 12dB/octave. The responses to the /da/ syllable in both the paradigms were isolated from that of the other stimuli by extracting the epochs, time locked to the /da/ stimulus. Epochs with peak amplitudes exceeding +/-35 μ V were rejected and the rest of the epochs were considered for further analysis.

After artifact rejection in the variable paradigm, the sequence of rejected and accepted epochs was used as a template to reject the corresponding epochs in the repetitive paradigm and vice versa. For example, if the response to the /da/ as the 12th stimulus in the variable paradigm was rejected, then the response to the 12th /da/ stimulus in the repetitive paradigm was also rejected. This was done in order to control the effect of variations in stimulus presentation order and neural refractoriness. The epochs were then averaged in the time domain to obtain brainstem responses of good signal to noise ratio and free from stimulus order effects.

The averaged brainstem responses were subjected to spectral analysis to analyse the amplitudes at the spectral components corresponding to the fundamental frequency (F0), second Harmonic (H2) and third Harmonic (H3) of the stimulus. This was done in a custom written program in Matlab. The waveforms were windowed from 20 ms to 110 ms using a 10% tapered Hanning window, and zero-padded to increase spectral resolution to 1 Hz. The zero-padded waveforms were then subjected to a Fast Fourier Transform, and the conjugate power spectrum was calculated. The amplitudes at F0, H2 and H3 were then analysed by averaging the magnitudes of ten bins (1Hz wide) around the F0, H2 and H3 frequencies.

The response analysis of ALLR involved band pass filtering of raw EEG using FIR filter with a 0.1 Hz high-pass cut off and a 30 Hz low-pass cut off , each with a slope of 12dB/octave. After filtering the EEGs were subjected to the artifact rejection procedure as used for speech ABR with a artifact rejection thresholds of +/- 75 μ V. The averaged waveforms derived from the accepted epochs, were baseline corrected and analyzed for their amplitude and scalp distribution. While, only the responses from Cz electrode site were considered for the measurement of amplitude of P1, N1, P2 and N2, the responses from all seven electrode sites were used to derive the scalp distribution. The averaged responses from the Cz electrode site were visually analyzed to mark the most prominent consecutively occurring positive peaks as P1 and P2. The negative troughs following P1 and P2 were correspondingly marked as N1 and N2. Peak latency and peak amplitude of these four peaks were noted down. On the other hand, scalp distributions were estimated by calculating the variance of each electrode from the overall variance of all the electrodes.

2.2.2 Contralateral Suppression of Otoacoustic Emissions

For the measurement of TEOAEs, the participants were made to sit on a comfortable chair in a sound treated room. ILO 292-USBII V6 (Otodynamics) was used for the recording of the oto-acoustic emissions.

The probe apparatus with an appropriate size tip was positioned in the left ear canal and adjusted to give flat frequency spectrum across all frequencies. TEOAE responses were averaged for 260 trains of clicks at an intensity of 70 dB peak SPL. The clicks were presented in a linear paradigm. Each train consisted of a train of four clicks. The duration of the click was 80 μ sec and its acoustic frequency range was 500 to 4000 Hz.

To trigger contralateral suppression, a white noise was used. The white noise was generated in Adobe Audition version 3.0 and presented to the contralateral ear (right ear) through a Sennheiser HDA200 headphones using a personal computer. The noise was calibrated to produce 40 dB SPL in a 2 cc coupler. Intensity of the noise was kept at 40 dB SPL. During the testing, in each participant, the middle ear admittance was monitored when the noise was presented to the contralateral ear, before recording the TEOAEs, to ensure that the middle ear reflexes were not elicited by the suppressor stimulus. Calibration was done regularly to ensure that the intensity of the suppressor did not change during the course of the study.

The TEOAEs in quiet and with contralateral noise were recorded twice each to counter the effect of test re-test variability. The OAEs were then analysed offline using the Kresge Echomaster software version 4.0 (Han Wen, 1988- Kresge Hearing Research Laboratory). The suppression magnitude was calculated in the latency region of 8ms to 20ms to minimise the artifactual interference of the stimulus ringing.

The two recordings each in quiet and contralateral noise condition were averaged. The suppression magnitude was calculated by the formula : $[(Aa - Ab) + (Ba - Bb)] / 2$. Here 'Aa' and 'Ab' are the buffer A responses of averaged TEOAE recorded without and with contralateral noise respectively. 'Ba' and 'Bb' are the buffer B responses of TEOAE recorded without and with contralateral noise respectively. The overall dB(RMS) suppression magnitude was analysed as a target parameter.

The schema of the experimental method used in the study is depicted in Figure 2.4.

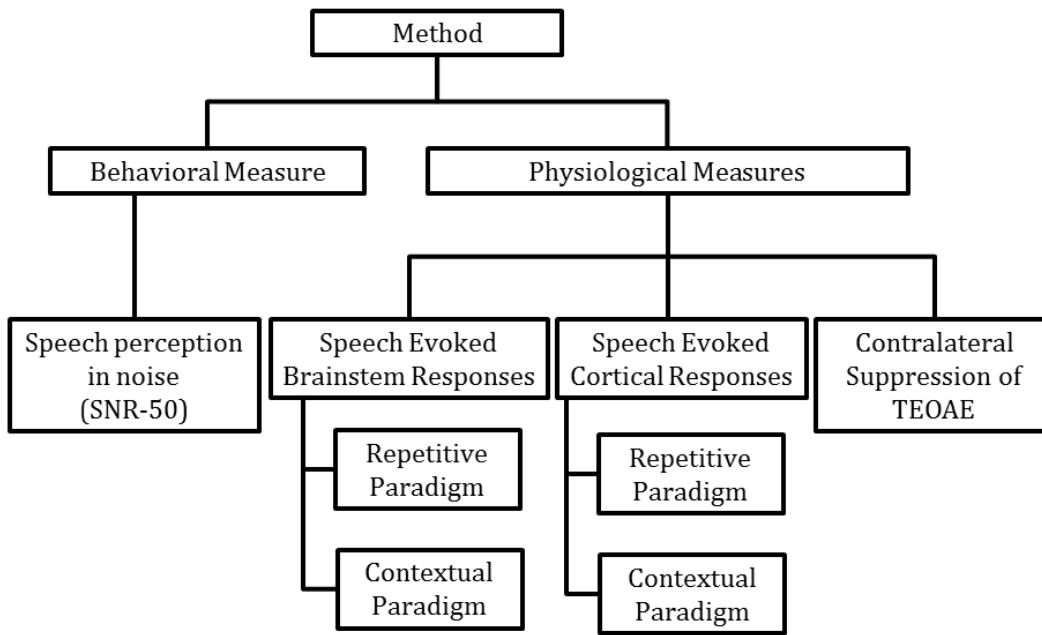


Figure 2.4: Schema of the test battery employed in the study.

The total duration for completion of all the experiments per participant was three and a half hours. The participants who could not sit for the whole duration of the experiments were tested in two sessions. The maximum gap between the first and the second session was three days.

2.4 Data Analysis

The data was analysed to compare the two participant groups in both behavioural and physiological measures. The statistical comparison was carried out using Statistical Package for Social Sciences Software (Version-17) and Systat-13. The group data were tested using Multivariate repeated measures ANOVA, with Bonferroni's pairwise comparisons, Independent t-test, Mann-Whitney U test, Pearson's Product-Moment correlation and stepwise linear regression to verify the objectives of the study.

Chapter 3

RESULTS

In the present study, the effect of paradigm and group was evaluated using multivariate repeated measures ANOVA and wherever applicable, pair-wise comparisons were performed using t-tests and Mann Whitney U test. Pearson's product-moment correlation was used to check for correlation among the different measures such as, SNR-50, CSOAE and, Context-dependent ABR and ALLR. Linear regression was used estimate a model to predict speech in noise perception from the measures of contextual encoding. The results of the study are reported under the following headings.

1. Results of Speech Perception in Noise
2. Results of Auditory Brainstem Responses
3. Results of Auditory Long Latency Responses
4. Results of Contralateral Suppression of Transient Evoked Otoacoustic Emissions
5. Results of Correlation

3.1 Results of Speech Perception in Noise

The mean and standard deviation of SNR-50 in the two groups is shown in Figure 3.1. It can be seen that the SNR-50 is lower in the younger group than that in the elder group. Independent sample t-test comparing the SNR-50 in the two groups showed that, the difference in SNR-50 was statistically significant [$t(58) = -10.536, p = 0.000$] in the younger group compared to the elder group.

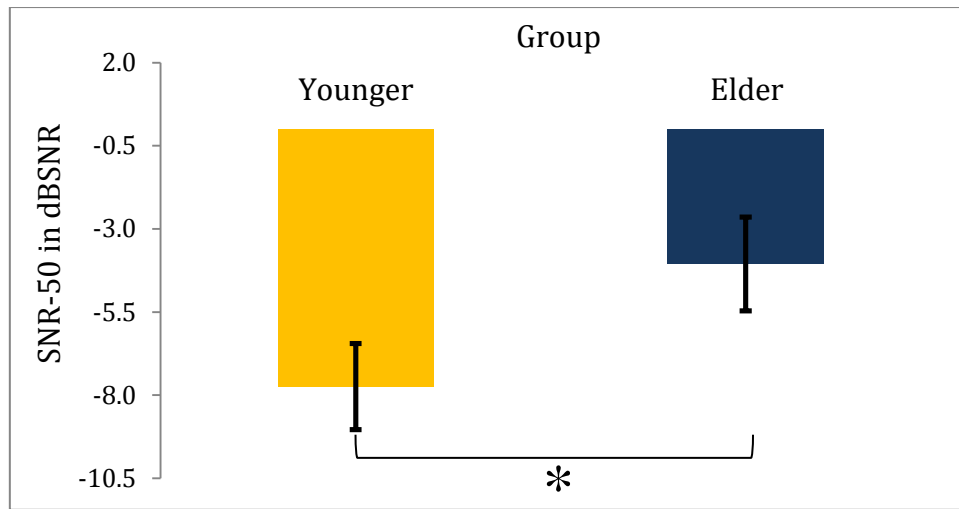


Figure 3.1: Mean and standard deviation of SNR 50 in the two groups. Asterisk represents significant difference with $p < 0.01$. Error bars show ± 1 SD.

3.2 Results of Auditory Brainstem Responses

The mean and standard deviations of the spectral magnitudes at F0, H2 and H3 for the two paradigms are shown in Figure 3.2. It can be seen that the spectral magnitudes are higher in the younger group than the elder group. It can also be seen that the spectral magnitude at F0 in the younger group is higher for the repetitive paradigm than the contextual paradigm. This is true for all except H3 in the younger group.

To assess the effect of group and paradigm on the speech evoked ABR, multivariate repeated measures ANOVA was performed on the ABR data with group as the between-subject factor and context as the within-subject factor. Results showed a significant main effect of group [$F(3,56) = 4.775, p < 0.01$] as well as paradigm [$F(3,56) = 3.128, p < 0.05$] on the spectral magnitudes of ABR. Univariate ANOVA showed a significant effect of group on the spectral magnitudes at F0 [$F(1,58) = 7.083, p < 0.05$], H2 [$F(1,58) = 6.535, p < 0.05$] and H3 [$F(1,58) = 6.351, p < 0.05$]. Similarly, there was a significant effect of paradigm only on F0 [$F(1,58) = 9.357, p < 0.05$] and not on H2 [$F(1,58) = 0.470, p > 0.05$] and H3 F0 [$F(1,58) = 0.323, p < 0.05$]. There was also a significant group x paradigm interaction [$F(3,56) = 4.695, p < 0.01$].

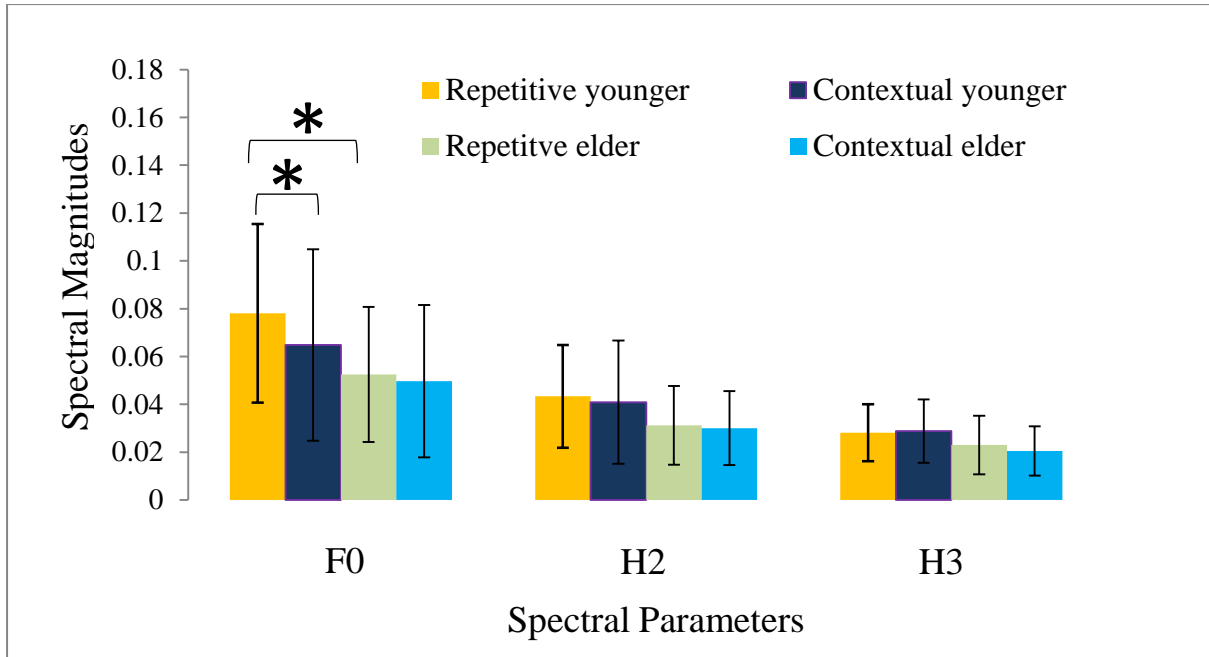


Figure 3.2: Mean and standard deviations of spectral magnitudes of the speech evoked ABRs in the two groups in the repetitive and contextual paradigms. The asterisk indicates significant difference with $p < 0.01$. Columns represent mean and error bars represent $\pm 1SD$.

Because, there was a significant interaction between group and paradigm, paired t-test was done to evaluate the effect of paradigm separately in each group and, independent t-test was done to evaluate the effect of group separately in each paradigm. The results of t-test are given in Table 3.1. Paired t-test with level of significance corrected (Based on the Bonferroni corrections) for the multiple comparisons showed significant effect of paradigm on F0 in the younger group, while, there was no significant effect of paradigm on H2 and H3 magnitudes. On the other hand, the elder group did not show significant difference between the two paradigms in any of the F0, H2 and H3 magnitudes.

The results of independent t-test are given in Table 3.2. Independent t-test with level of significance corrected for the multiple comparisons showed significant effect of group on F0 in the repetitive paradigm, while, there was no significant effect of group on F0 in the contextual paradigm. In addition, there was no significant effect of group on the H2 and H3 magnitudes in either of the paradigms.

Table 3.1: Results of paired t-test comparing spectral magnitudes of ABR between the two paradigms in the two groups

Group	Parameter	df	t	p
Younger	F0	29	7.215	0.000
	H2	29	0.683	0.500
	H3	29	-0.417	0.680
Elder	F0	29	0.489	0.629
	H2	29	0.303	0.764
	H3	29	0.934	0.358

Table 3.2: Results of independent t-test comparing spectral magnitudes of ABR between the two groups in the two paradigms

Group	Parameter	df	t	p
Repetitive	F0	58	2.982	.004
	H2	58	2.456	.017
	H3	58	1.635	.108
Contextual	F0	58	1.613	.112
	H2	58	1.980	.052
	H3	58	2.706	.009

The effect of paradigm on speech ABR between the two groups was further evaluated by determining the differences in the spectral magnitude between repetitive and contextual paradigm. The difference-magnitudes thus obtained were operationally defined as contextual index of ABR. The contextual index was determined separately for F0, H2 and H3 magnitudes in the two groups of participants. The mean and standard deviation of the contextual index on the spectral magnitudes are shown in Figure 3.3. It can be seen from the figure that the mean contextual index is higher in the younger group compared to the elder group, at F0 and H2. Whereas, mean contextual index was higher in the elder group compared to the younger group at H3 do not seem to be different in the two groups. It can also be seen that the mean standard deviations are greater than the mean spectral magnitudes, thus a Levene's test of equality of variances

was performed before statistical treatment. Levene's test revealed that the variances across the groups were not equal; therefore, Mann-Whitney U test was used to compare the contextual index in the two groups. The results of Mann-Whitney U test are given in Table 3.3. The results showed that the contextual index was significantly different only at F0 and not at H2 and H3. The contextual index on H2 and H3 however, did not differ significantly between younger and elder groups.

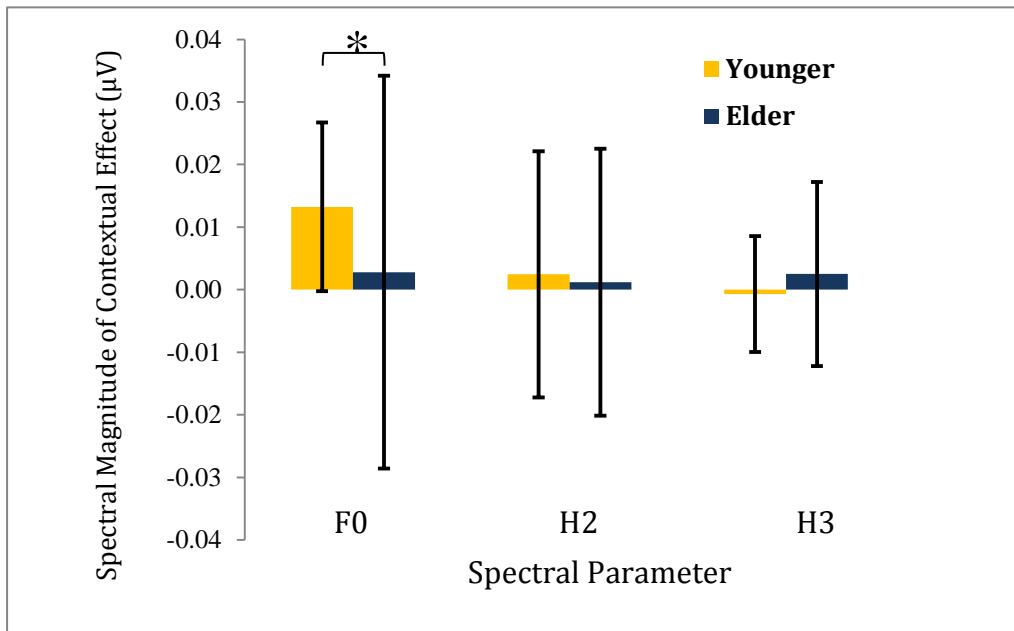


Figure 3.3: Mean and standard deviation of contextual index at F0, H2 and H3 in the younger and the elder group. The asterisk indicates significant difference with $p < 0.01$. Columns represent mean and error bars represent $\pm 1SD$.

Table 3.3: The result of Mann-Whitney U test comparing contextual index on ABR in the younger and elder groups.

Contextual effect at	Z	Asymp. Sig. (2-tailed)
F0	-2.646	0.008
H2	-0.399	0.690
H3	-0.362	0.717

3.3 Results of Auditory Long Latency Responses (ALLR)

3.3.1 Results of amplitude of ALLR

The mean and standard deviation of peak amplitudes of P1, N1, P2 and N2 in the two groups for the contextual and repetitive paradigms are shown in Figure 3.4. From the figure, it can be seen that mean amplitudes did vary depending on the context as well as group. On comparison between the paradigms, it was seen that the mean amplitudes were lesser in the repetitive paradigm compared to the contextual paradigm in both the groups, for all four peaks (P1, N1, P2 and N2) in the younger group. Similar result was obtained in the elder group except for N2. In N2 of the elder group, mean amplitudes were higher in the repetitive paradigm compared to the contextual paradigm.

Comparison of the two groups showed that the mean amplitudes were higher in elder group compared to younger group in P1, N1 and P2. This was true in both the stimulus paradigm. In contrast, N2 was higher in the contextual paradigm than in the repetitive paradigm in the younger group. The amplitudes of P1, N1 and P2 but the N2 were higher for the contextual paradigm than the repetitive paradigm in the elder group.

To assess the effect of group and context on the speech evoked ALLR peak amplitudes, multivariate repeated measures ANOVA was performed on the ALLR amplitude data with group as the between subject factor and context as the within subject factor. The peak amplitudes of ALLRs evoked by syllable /da/ showed a significant main-effect of group [$F(4,55) = 8.371, p = 0.000$] as well as paradigm [$F(4,55) = 22.914, p = 0.000$]. The main effect of paradigm was seen on the amplitudes of P1 [$F(1,58) = 6.25, p = 0.015$], N1 [$F(1,58) = 62.159, p = 0.000$] and P2 [$F(1,58) = 4.742, p = 0.034$] but not N2 [$F(1,58) = 2.735, p = 0.104$]. Effect of group was seen on P1 [$F(1,58) = 5.014, p < 0.05$], P2 [$F(1,58) = 6.310, p < 0.05$] and N2 [$F(1,58) = 12.397, p < 0.05$] and not on N1 [$F(1,58) = 2.938, p > 0.05$]. Assessment of the group \times paradigm interaction effect revealed no significant interaction [$F(4,55) = 2.429, p > 0.05$].

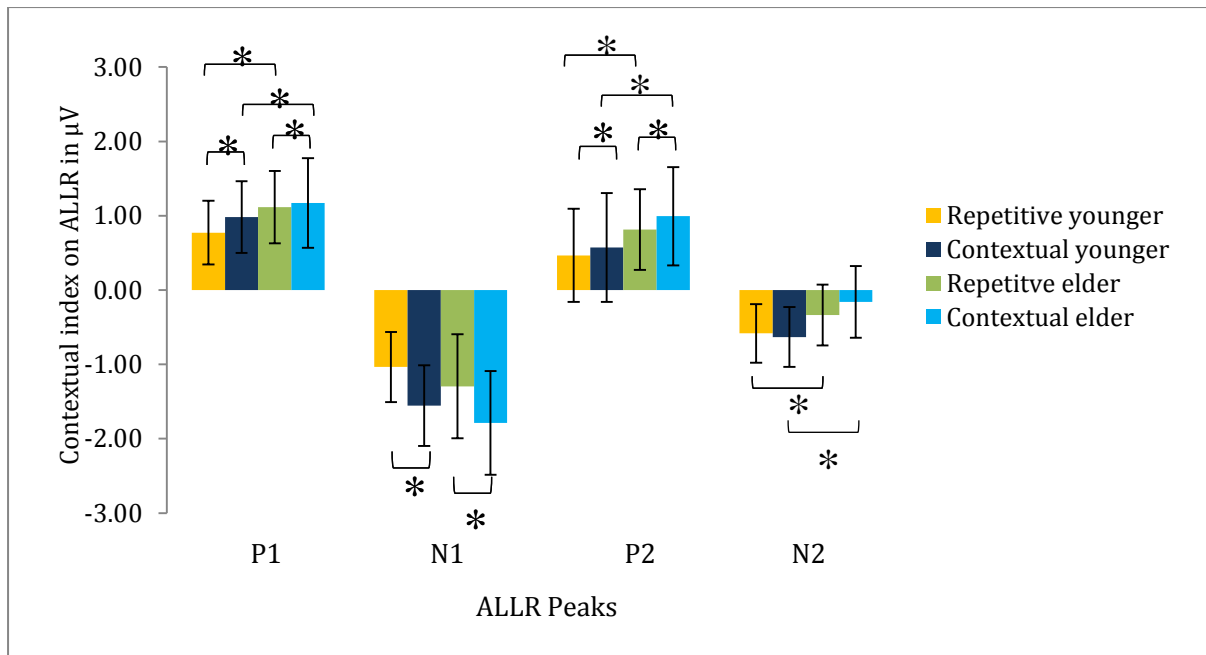


Figure 3.4: Mean and standard deviation of peak amplitudes of LLR for the two paradigms in the two groups. The asterisk indicates significant difference with $p < 0.05$. Columns represent mean and error bars represent $\pm 1SD$.

The effect of paradigm on ALLR peak amplitudes between the two groups was further evaluated by determining the differences in the amplitudes between repetitive and contextual paradigms. The difference-amplitudes thus obtained were operationally defined as contextual index of ALLR. The contextual index was determined separately for P1, N1, P2 and N2 amplitudes in the two groups of participants. The mean and standard deviation of the contextual index on the peak amplitudes are shown in Figure 3.5.

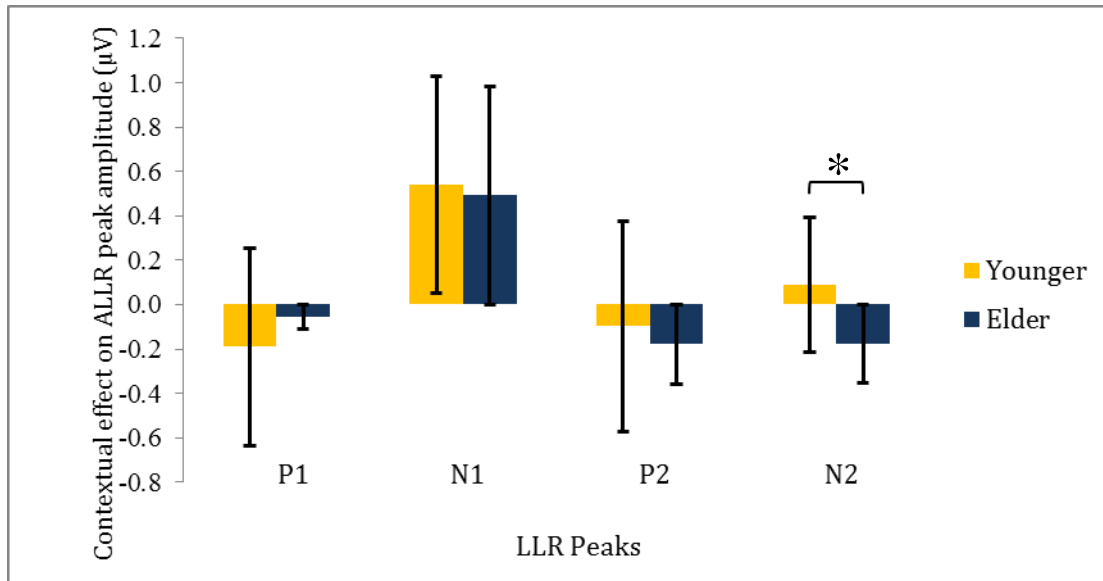


Figure 3.5: The mean and standard deviation of the peak amplitude differences of ALLR between the two paradigms (peak latencies in the repetitive paradigm – peak latencies in the contextual paradigm) for the two groups. Asterisk indicates significant difference at $p < 0.05$.

Table 3.5: Independent sample t-test results of the comparison of contextual effect on peak amplitudes in LLR between the two groups. The shaded cell are significant at $p < 0.05$, 0.01

Parameter	df	t	p
P1	-1.235	58	0.222
N1	0.383	58	0.703
P2	0.618	58	0.539
N2	3.047	58	0.003

It can be seen from Figure 3.5 that the maximum contextual index was higher in younger group compared to elder group in P1 and N1. Whereas, it was higher in elder group compared to the elder group in P2 and N2. From the figure, it can also be seen that the standard deviations are greater than the mean peak amplitudes, thus, a Levene's test of equality of variances was performed before statistical treatment. Levene's test revealed that the variance between the groups was equal. Independent samples t-test test was used to compare the contextual index in the two groups. The results of independent t-test are given in Table 3.5. The results showed that, contextual index of N2 was statistically significant between the two groups. The mean differences however, were not significantly different in P1, N1 and P2.

Scalp Distribution of ALLR

The topographic maps of scalp distribution of the grand averaged cortical responses were plotted by deriving the variance in each channel with the overall variance at the time-samples corresponding to the peaks P1, N1, P2 and N2. Figure 3.6 shows the topographic plots of the ALLRs in the two groups for the two paradigms.

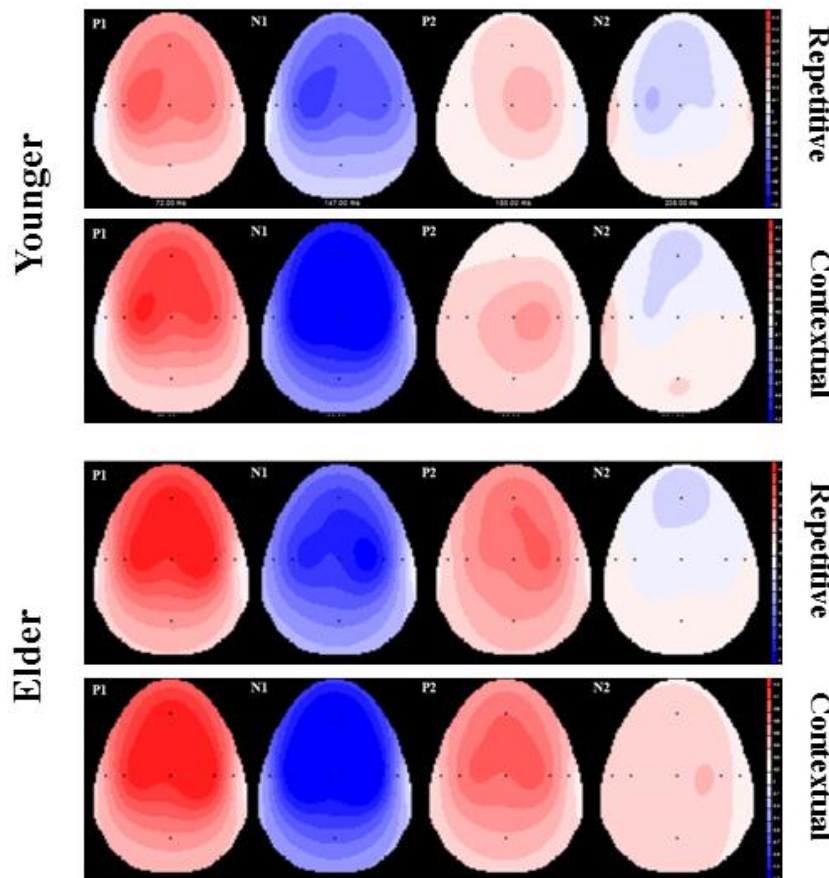


Figure 3.6: Scalp topographic maps of the distribution of ALLR for the two paradigms in the two groups. The scale warm to cold colour ranges from $+1.2\mu V$ to $-1.2\mu V$.

It can be seen from Figure 3.6 that there is marked difference in distribution of cortical activity between the two paradigms in both the groups. The scalp distribution is more widespread in the contextual paradigm compared to the repetitive paradigm in both the groups. The younger group showed more of left hemisphere activation in the latency region of P1, N1 and N2, while there was an activation skewed to the right hemisphere in the P2 region. In the contextual paradigm, there was a spread in the activation from the left hemisphere towards the right

hemisphere for maps corresponding to P1 and N1 latency region and a leftward activation in the P2 latency region.

The elder group showed activation skewed to the right hemispheres for P1, N1 and P2, while the N2 did not show any skewed activation pattern. Contrary to the younger group, the elder group showed more of a right hemisphere activation for P1, N1 and P2 regions. There was a right to left spread of activation for the contextual condition in the elder group. In the contextual paradigm there was a spread in the activation from the right hemisphere towards the left hemisphere for maps corresponding to P1, N1, P2 and N2 latency region.

3.4 Results of Contralateral Suppression of Transient Evoked Otoacoustic Emissions

The magnitude of suppression of OAE was computed from the global OAE magnitudes in the contralateral noise and no noise condition. The Mean and standard deviation of suppression magnitudes in the two groups are shown in Figure 3.7. It can be seen that the mean suppression magnitude in the young group was higher than that seen in the elder group. Independent sample t-test revealed a significant difference [$t(58) = 5.518, p = 0.000$] in suppression magnitude between the two groups.

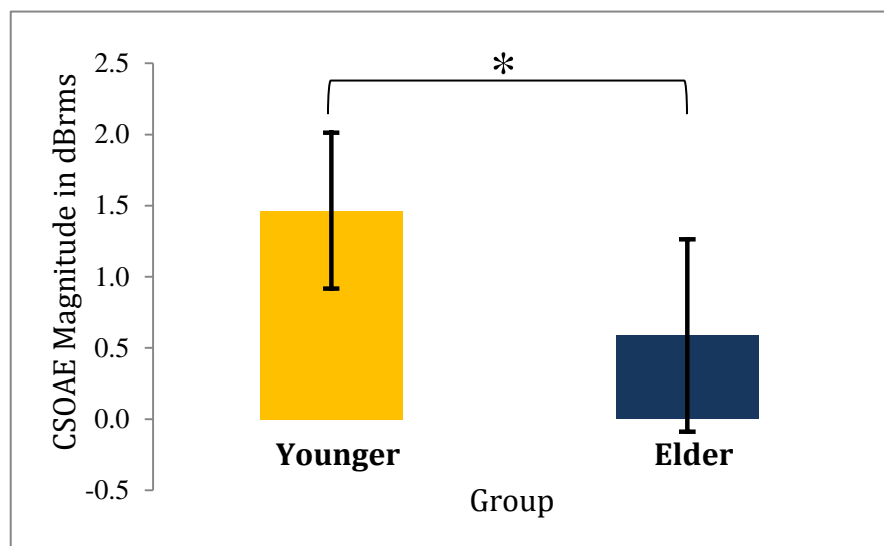


Figure 3.7: Mean and standard deviation of CSOAE magnitude in the younger and elder group. Asterisk represent significant difference at $p < 0.01$. Error bars indicate ± 1 SD.

3.5 Results of Correlation

To derive the relationship between physiological measures (speech ABR, its contextual effect, speech ALLR, its contextual effect and contralateral suppression of OAE) and speech perception in noise, each of the physiological measures was correlated with speech perception in noise using Pearson's product-moment correlation. Similarly, to derive the relationship within physiological measures, correlations were carried out among different physiological measures.

3.5.1 Correlation between Physiological Measures and SNR 50

Results of correlation between Speech ABR and SNR-50

Figure 3.8 shows the scatter plot of SNR-50 and contextual effect on F0 spectral magnitude in speech ABR. It can be seen from the scatter plot that the SNR-50 was lower when the ABR spectral magnitudes were higher and vice-versa. Thus, there seems to exist an inverse relationship between the ABR spectral magnitudes and SNR-50.

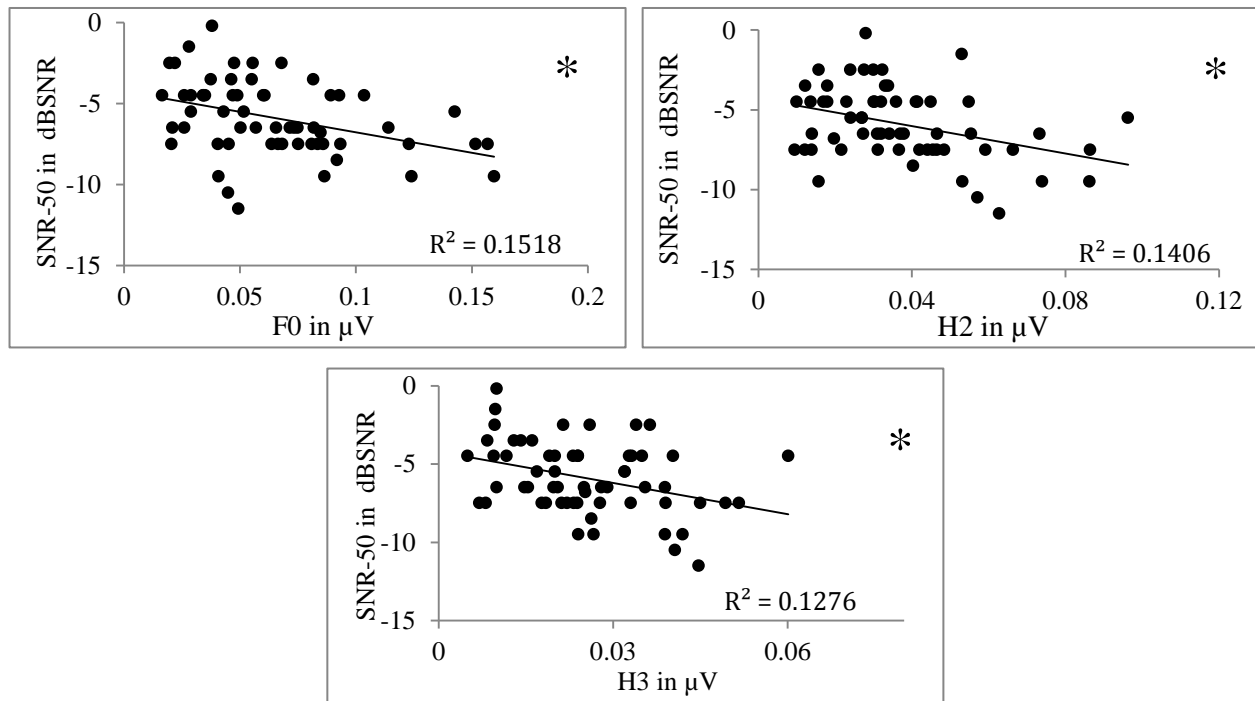


Figure 3.8: Scatter-plots of SNR-50 with the spectral magnitudes of speech ABR. The asterisk indicates panels with significant correlation ($p < 0.05$).

Table 3.4 gives the results of Pearson's product-moment correlation of SNR-50 and spectral magnitudes of speech ABR. Results showed a significant negative correlation between SNR-50 and spectral magnitudes of speech ABR. This was true for F0, H2 as well as H3.

Table 3.6: Pearson's correlation coefficient showing the statistical relation between SNR-50 with the spectral magnitudes of speech evoked ABR at F0, H2 and H3

		F0	H2	H3
SNR50	r - value	-0.390**	-0.375**	-0.357**
	p - value	0.002	0.003	0.005
Note: ** indicates significance at $p < 0.05$				

Results of Correlation between Contextual index of Speech ABR and SNR-50

Figure 3.9 shows the scatter plot of SNR-50 and contextual index of speech ABR at F0, H2 and H3. It can be seen from the figure that, the SNR-50 decreases as the amplitude of contextual index on F0 increases. The same trend however is not seen in the contextual index at H2 and H3 magnitudes. Table 3.7 gives the results of Pearson's correlation between contextual index of speech ABR and SNR-50. Results of Pearson's product-moment correlation showed a significant negative correlation between SNR-50 and the contextual index at F0 (F0diff), while the other two harmonics did not show any significant correlation.

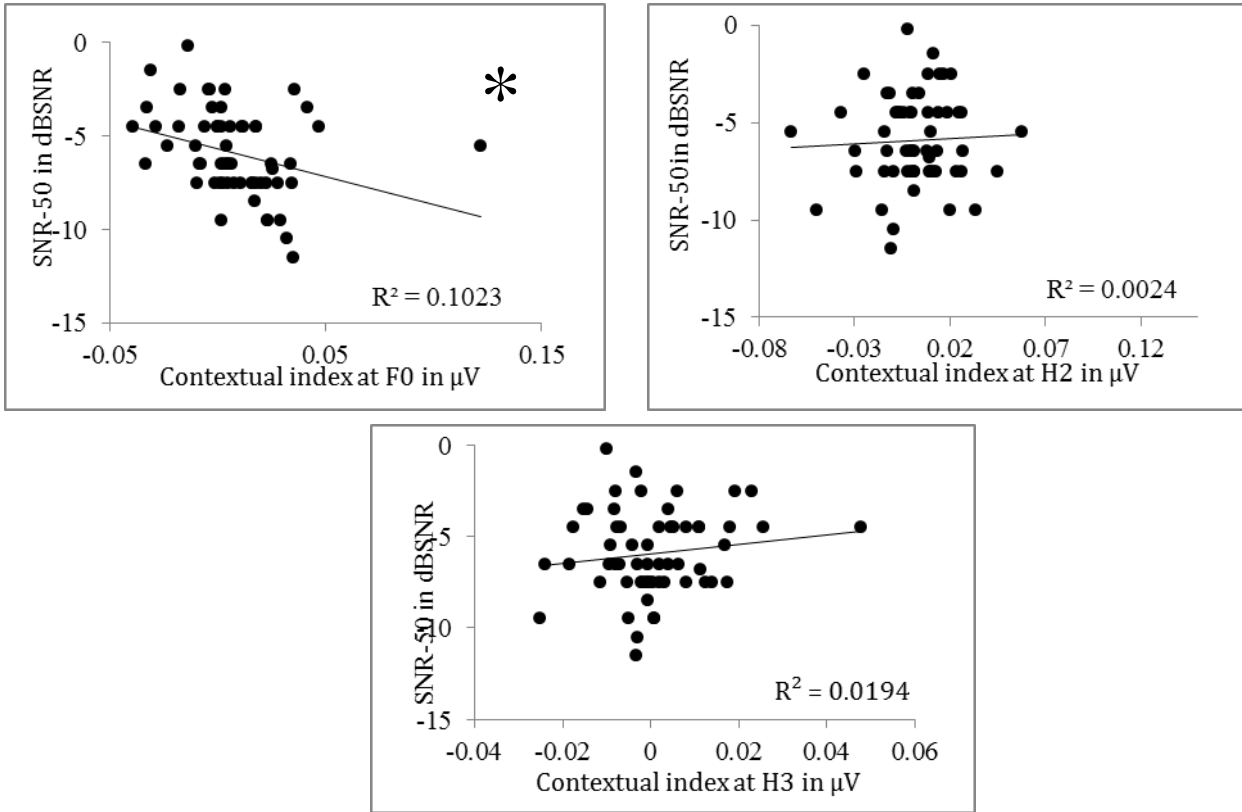


Figure 3.9: Scatter-plot of SNR-50 across contextual index at F0, H2 and H3 in speech evoked ABR. The Asterisk marks the panel with correlation significant at $p < 0.05$.

Table 3.7: Pearson's correlation coefficient for spectral magnitudes of contextual effect in speech evoked ABR

		F0diff	H2diff	H3diff
SNR50	r - value	-0.320	0.049	0.139
	p - value	0.0127	0.711	0.290

Correlation between ALLR and SNR-50

The scatter plots showing the distribution of the amplitudes of P1, N1, P2 and N2 in relation to SNR-50 are shown in Figure 3.10. It can be seen that scatter plots do not show any clear discernable trend in any of the ALLR peaks when related with SNR-50. The data was statistically tested using Pearson's product-moment correlation and the results did not show significant correlation between peak amplitudes of ALLR

and SNR-50. This was true for all the four peaks. The correlation coefficients are given in Table 3.8.

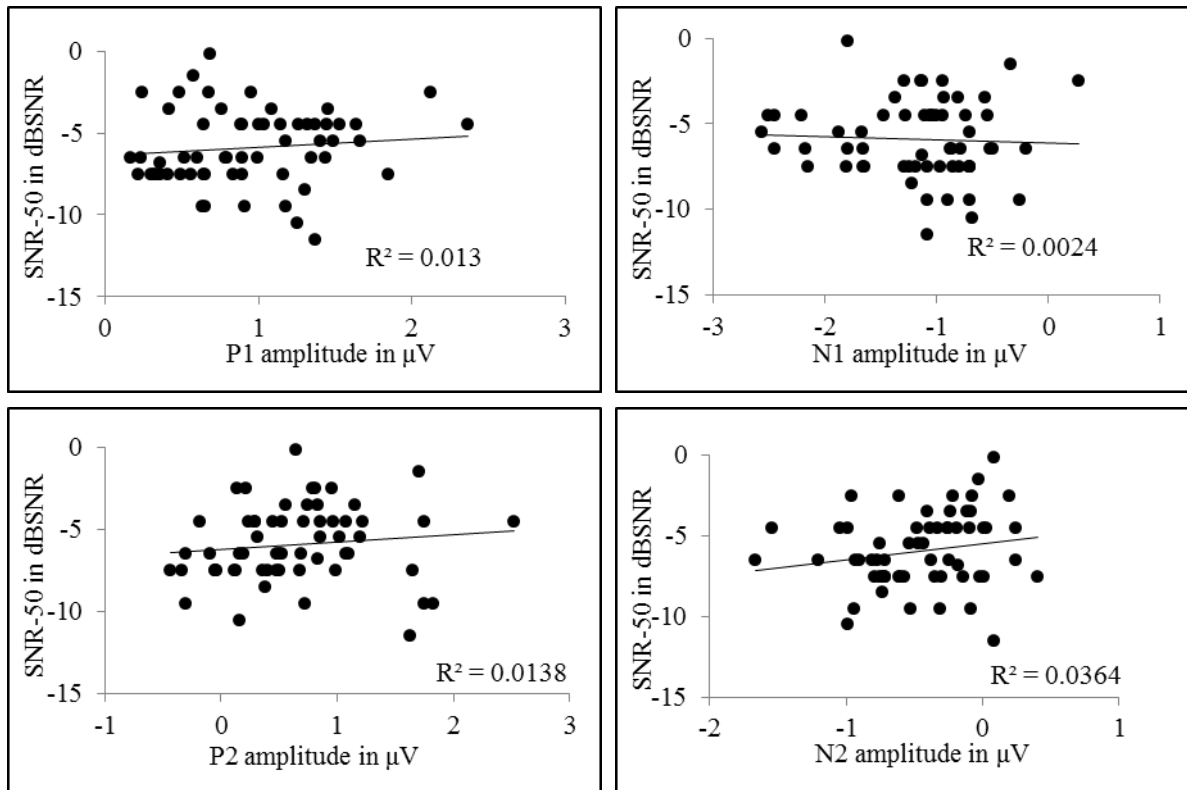


Figure 3.10: Scatter plots of ALLR amplitudes with SNR-50.

Table 3.8: Results of Pearson's product-moment correlation correlating peak amplitudes of ALLR (P1, N1, P2 & N2) with SNR-50

		P1	N1	P2	N2
SNR-50	r-value	0.114	-0.049	0.118	0.191
	p-value	0.386	0.711	0.371	0.144

Correlation between Contextual Index of ALLR and SNR-50

The scatter plots showing the distribution of the contextual index of P1, N1, P2 and N2 amplitudes in relation to SNR-50 are shown in Figure 3.11. It can be seen that scatter plots do not show any clear discernable trend in any of the ALLR peaks when related with SNR-50 except for N2. As the contextual index of N2 increased, the SNR-50

value decreased. The data was statistically tested using Pearson's product-moment correlation and the results did not show significant correlation between contextual index of ALLR at P1, N1 & P2. N2 however, showed a significant correlation with SNR-50. The correlation coefficients are given in Table 3.8.

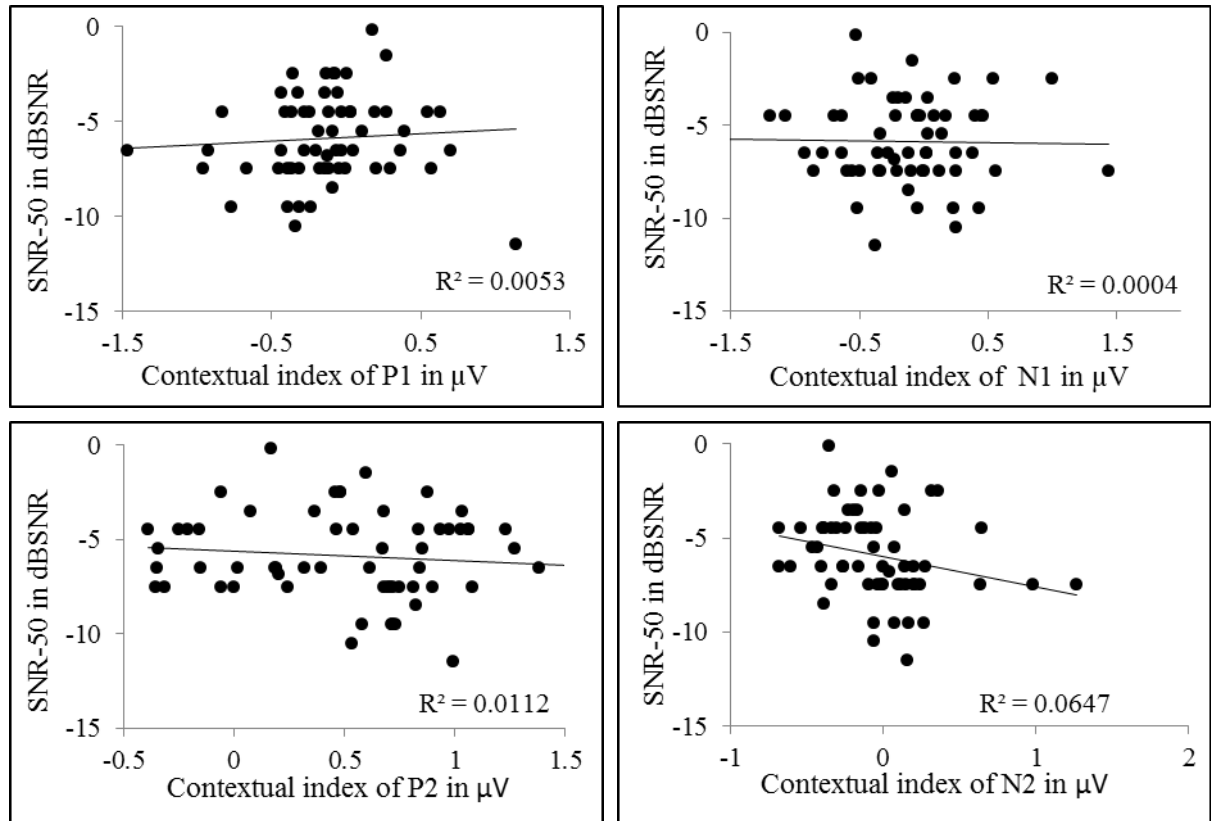


Figure 3.11: Scatter-plots of contextual index at ALLR peak amplitudes with SNR-50.

Table 3.9: Results of Pearson's product-moment correlation correlating contextual index of ALLR with SNR-50

		P1	N1	P2	N2
SNR-50	r - value	0.073	-0.106	-0.020	-0.254
	p - value	0.581	0.420	0.877	0.050

Correlation of CSOAE and SNR-50

The scatter-plot of CSOAE magnitude and SNR-50 are shown in Figure 3.12. It can be seen from the figure that when the CSOAE magnitude was high when the SNR-50 was low and vice-versa. There seems to be an inverse relationship between SNR-50 and CSOAE magnitude. To check for the statistical significance of this relationship, Pearson's product moment correlation was carried out. Pearson's product-moment correlation showed a significant negative correlation between CSOAE magnitude and SNR-50. There was a high significant negative correlation [$r = -0.658$, $p = 0.000$] between the CSOAE and SNR-50.

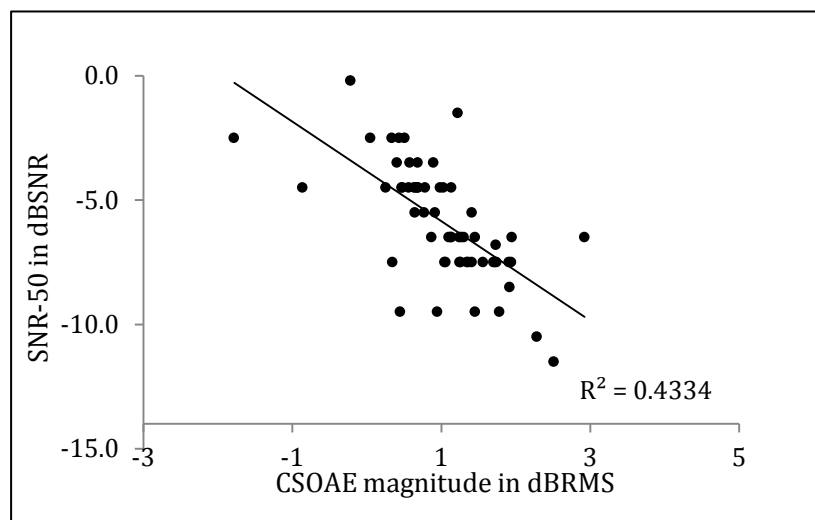


Figure 3.12: Scatter-plot of CSOAE magnitude in relation to SNR-50.

3.5.2 Correlations among the Physiological Measures

Pearson's product-moment correlation was used to evaluate the correlation between the different physiological measures of top-down modulation. Table 3.10 gives the correlation coefficients of the physiological measures of top-down modulation. Pearson's correlations revealed that there was no significant correlation between any of the physiological measures of top-down modulation.

Table 3.10: Pearson's product-moment correlation of different physiological measures of top-down modulation

	Statistical output	P1diff	N1diff	P2diff	N2diff	CSOAE
F0diff	r - value	-0.053	0.117	0.018	0.078	0.044
	p - value	0.688	0.374	0.893	0.553	0.736
H2diff	r - value	-0.025	-0.034	-0.059	-0.068	-0.108
	p - value	0.849	0.794	0.655	0.604	0.413
H3diff	r - value	-0.050	0.081	0.008	0.139	-0.233
	p - value	0.707	0.540	0.953	0.290	0.073
CSOAE	r - value	0.035	0.164	0.039	0.146	
	p - value	0.793	0.211	0.768	0.265	

3.11. Prediction of Speech Perception in Noise from the Physiological Measures of Top-Down Modulation

The specific physiological measures that correlated with speech perception in noise (CSOAE, Contextual index of ABR at F0, and Contextual index of N2 in ALLR) were used to determine the predictability of speech perception in noise from the physiological measures. Linear regression was done to statistically test it. The contextual index of N2 amplitude of ALLRs was not a significant predictor and therefore was excluded from further analysis. Consequent to this, contextual index at F0 in speech ABR and CSOAE were found to be significant predictors of SNR-50. The CSOAE alone predicted 43.3% (R^2 value) variance in the SNR-50 whereas contextual F0 effect and CSOAE together predicted 51.8% (R^2 value) variance in the SNR-50. The standardized β -coefficients showed that CSOAE predicted greater variance ($\beta = -0.645$) in the SNR-50 than the contextual effect on F0 ($\beta = -0.291$). The regression model is given in equation 3.1, and the fitted model plot is shown in Figure 3.13. Based on Figure 3.13 it can be seen that the regression equation does not explain the variance in few of the outliers.

$$\text{SNR50} = -1.966 \times \text{CSOAE} - 27.272 \times \text{F0diff} - 3.664 \quad \text{..Equation 3.1}$$

Where, SNR-50 is the variable to be predicted, F0diff is the contextual effect on F0 in speech ABR and CSOAE is the OAE suppression magnitude, and both are the predicting variables. The coefficients of the predicting variables are the un-standardised regression coefficients.

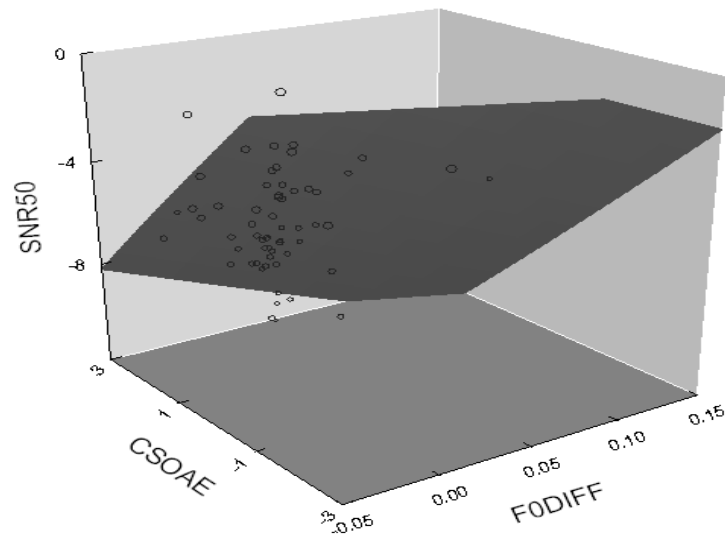


Figure 3.13: Fitted model plot of equation 3.1 to predict SNR-50.

Chapter 4

DISCUSSION

The present research work studied the effect of neurophysiological measures of top-down modulation of auditory perception in humans and their relation with speech perception in noise. The context dependent brainstem encoding, cortical encoding and, CSOAE served as the neurophysiological measures of top-down modulation. These measures were evaluated in younger and older individuals with normal hearing sensitivity. This was done to observe the differences in these measures if any, in individuals with good and poor speech perception in noise (SPIN). The results showed a significant relationship between speech-in-noise perception and the brainstem measures of top-down modulation. The findings of the study have been discussed under the following headings:

1. Speech in Noise Perception
2. Context-dependent Brainstem Encoding of speech
3. Context-dependent Cortical Encoding of Speech
4. Contralateral Suppression of OAE
5. The relationship between speech perception in noise and auditory brainstem and cortical responses
6. The relationship between speech perception in noise and context dependent auditory brainstem and cortical responses
7. The Relationship between speech perception in Noise and CSOAE

4.1 Speech in Noise Perception

The signal-to-noise ratio for 50% identification of sentences (SNR-50) was estimated in the younger and the older groups to quantify the speech perception in noise ability. The younger group required lower SNR than the elder group to achieve equivalent speech identification scores. This means younger group was more resistant to the effects of noise on perception of speech than the elder group. The higher SNR-50 in the elder group signifies poorer speech in noise perception in the elder group in spite of normal peripheral hearing sensitivity. This was consistent with studies of speech in

noise perception in elder individuals (Gordon-Salant & Fitzgibbons, 1993, 1997; Tremblay, Piskosz,& Souza, 2002). A variety of reasons have been proposed for this poor speech in noise perception, some of them being impaired central auditory processing, cognitive processing difficulties, and attention deficits (Frisina & Frisina 1997; Gordon-Salant & Fitzgibbons, 1997; Tremblay et al., 2002; Tun et al., 2002). The current study investigated the role of the top-down modulatory influence on the speech in noise perception. The relationship between the top-down modulatory measures and speech perception in noise is discussed in the subsequent sections.

4.2 Context-dependent Brainstem Encoding of speech

The auditory brainstem is an important juncture in the central auditory pathway and transduces high fidelity temporal features of sound through accurate encoding (Anderson et al., 2011;Anderson et al., 2010a,2010b). These temporal aspects of speech are reported to be important in segregating the desired signal from the background and the F0 (pitch) of the signal is one of the primary parameter in this process (Assmann & Summerfield, 1987; Bird & Darwin, 1998).

The encoding of timing in the brainstem is further influenced by the context of syllables. The current study showed that the encoding of F0, when the stimulus /da/ was presented repetitively was enhanced than when presented in the context of other syllables. When syllables are presented repetitively, based on the on-going sound statistics, the brain predicts the subsequent input and fine-tunes the brainstem encoding of the predictable syllable. However, when a syllable is presented in the context of other syllables the brain cannot predict the incoming syllable and therefore does not fine-tune the brainstem encoding. This process of deriving the on-going sound statistics and accordingly modulating the brainstem responses is reported to be mediated by the corticofugal efferent pathway (Chandrasekaran & Kraus 2009; Parbery-Clark et al., 2011; Strait et al., 2012).

The corticofugal modulation model explains that the auditory cortex improves the signal encoding by modulating the response properties of the brainstem neurons mediated by the cortico-fugal pathway (Winer, Diehl & Larue, 2001; Suga et al., 2002; Coomes & Schofield, 2004; Meltzer & Ryugo, 2006). This ability to modulate the

responses of the sub-cortical neurons, helps in rapidly adapting to the changing listening environments, and challenging listening situations, as has been found in animal models (Atiani et al., 2009). Therefore, it can be inferred that the contextual effect at F0 seen in the present study can serve as an index of online cortico-fugal regulatory mechanism

In the current study, it was also seen that the contextual brainstem encoding was present in the younger participants but not in the elder participants. The absence of contextual encoding was evidenced by no difference in the encoding of F0, H2 and H3 in the two paradigms. This implies that the ability of the brainstem to differentially process repetitively and contextually presented syllables is impaired in elderly individuals. Elderly individuals have been reported to have deficits in perceptual sound stream segregation (Hannah, Allan & Young, 2012; Ben-David, Tse & Schneider, 2012). Therefore, the absence of contextual effect in elderly individuals suggests that sound stream segregation and cortico-fugal regulatory mechanisms may be related. However, this relation can only be justified by correlating the two (refer to section 4.6). Additionally, poorer brainstem encoding of the timing features in elder participants was seen in the elder studies, in consonance with the earlier studies (Anderson et al., 2010a, 2011b).

4.3 Context-Dependent Cortical Encoding of Speech

The contextual cortical encoding, unlike the contextual brainstem encoding showed decreased ALLR amplitude in the repetitive paradigm compared to contextual paradigm. This is in consonance with earlier literature (Naatanen & Picton, 1987; Brosch & Schreiner, 1997; Calford & Semple, 1995; Karhu et al., 1997; Boutros & Bilger, 1999; Bartlett & Wang, 2005; Brosch & Scheich, 2002). Wang et al. (2010) proposed that the enhancement in the cortical responses is due to the presence of novelty detection mechanisms in the cortex, which enhance the encoding of sounds presented in the context of other syllables. Similarly, Bartlett and Wang (2005) reported that there is a reduction in the amplitude of cortical responses in primate auditory cortex due to forward masking when the acoustic characteristics of the subsequent stimuli were similar. Summerfield et al. (2008) based on their study of repetition suppression using

fMRI, postulated that the stimulus repetition leads to fulfilling of perceptual expectancy, leading to a lesser processing demand on the cortical neurons hence, suppression. On the other hand, a novel or an unpredictable stimulus would lead to a greater processing demand on the cortical neurons and hence greater activation. This context-specific enhancement and ALLR can thus be considered as a feature important for normal auditory processing.

Another interesting finding in the present study is that the ALLR amplitudes were significantly higher in the elder group compared to the younger group. This finding may be attributed to the age related changes to the poorer repetition related suppression (Boutros & Belger, 1995; Karhu et al., 1997; Rosburg et al., 2004) due to the large number of stimuli presentations. That is, age related changes do occur and influence the regularity detection mechanisms at the cortical level which in turn may have consequence on the sound-stream segregation. Further studies analysing the effect of number of stimulus presentations on ALLR would be necessary to validate this observation. In contrast to the results of ALLR in the two paradigms, comparison of the contextual index between groups showed that there was a higher contextual effect of N2 in elder group compared to younger group. The exact physiological mechanisms for this finding is not clear and needs further research.

Based on the topographic maps it was found that, there was a difference in the activation for the two paradigms in both the groups. The contextual paradigm showed increased area of activation on the scalp than the repetitive paradigm. This suggests that the generators of ALLR in the contextual paradigm are more widely distributed or are more in number than the generators in the repetitive paradigm. Also, there was a difference in the activation maps for the contextual encoding of cortical responses between the two groups. In spite of the fact that, amplitude of the contextual effect did not vary in the two groups, there were differences in the activation maps. This hints towards a possible compensation or re-organization of the cortical processing (Merzenich et al., 1984; Xerri, Stern & Merzenich, 1998; Pons et al., 1991). Put simply, the cortical structures in the elder individuals try to compensate for the decline in processing by engaging other non-specific areas for processing the sound streams. This is quite clear from the fact that the younger group engage the activation of the right hemisphere in the contextual paradigm, in contrast to the left hemisphere activation in

the repetitive paradigm. The elder group on the other hand, had greater activation in the right hemisphere in the repetitive paradigm and engaged the left hemisphere too in the contextual encoding.

4.4 Contralateral Suppression of OAE

The contralateral suppression of otoacoustic emissions mediated by the medial olivocochlear pathway has been an important physiological measure of efferent functioning and has been demonstrated to be important for speech perception (Kawase & Libermann, 1993; Kawase, Delgutte & Libermann, 1993; Kumar & Vanaja, 2004). The suppression was higher in the younger group than the elder group in the current study. This was consistent with the previous findings of reduced CSOAE magnitude in aged individuals (Parthasarathy, 2001; Kim et al., 2002; Mukari & Mammat, 2008). This finding was seen even in the absence of any significant hearing loss in the elder group. The reduced CSOAE could be attributed to age related decline in the functioning of medial olivocochlear efferent pathway (Parthasarathy, 2001; Kim et al., 2002; Mukari & Mammat, 2008). The normal medial efferent system helps in auditory perception by modulating the responses in the auditory nerve and causing an anti-masking phenomenon, which helps in enhancing the on-going signal in the presence of noise (Giraud et al., 1995; Liberman & Guinan, 1998). This modulatory mechanism was impaired in the elder group, which is one of the factors, which affect auditory perception.

4.5 Relationship between Speech Perception in Noise and Auditory Brainstem and Cortical Responses

The SNR-50 correlated with the spectral magnitudes of speech ABR at F0, H2 and H3. This finding is consistent with earlier studies (Parbery-Clark et al., 2009; Anderson & Kraus, 2010; Bidelman & Krishnan, 2010; Song et al., 2010) which reported that accurate encoding of timing information is important for the perception of speech in noise. The current study also showed that speech perception in noise and brainstem encoding were poorer in the elder group than the younger group. This adds weight to the fact that the brainstem encoding of pitch is vital for perception of speech in noise. This encoding of pitch helps in separating the desired speech stream from the rest by tagging onto the voice pitch of the desired speech stream and extracting it from

background (Parbery-Clark et al., 2009; Anderson & Kraus, 2010; Bidelman & Krishnan, 2010; Song et al., 2010).

The amplitude of speech evoked ALLR did not show any relationship with the SNR-50. This was consistent with the observed similarity in the ALLR parameters in the two groups. It can be observed that the ABR showed a good relationship with the SNR-50 and not the ALLR. This could possibly be because of the precision of encoding of stimulus features in the brainstem, which is affected by the most subtle of the processing problem. On the other hand, the ALLRs are the onset responses, with a larger mean deviation and, very subtle deficits are not evidently visible. Alternately, it can be thought that, the elder group may have developed subtle cortical processing deficits, which might have been overcome by the brain's ability to re-organise its functions. Any such reorganization by engaging the other non-specific regions of the brain (Merzenich et al., 1984; Xerri, Stern & Merzenich, 1998) would mask out the differences in processing.

4.6 The relationship between speech perception in noise and context dependent auditory brainstem and cortical responses

The contextual effect on F0 in ABR was significantly related to SNR-50. Individuals with greater contextual effect on F0 showed better speech in noise perception evidenced by their low SNR-50. This is consistent with the studies by Chandrasekaran and Kraus (2009), Parbery-Clark et al. (2011) and Strait et al. (2012). The correlation between speech in noise perception and contextual brainstem encoding, points towards the role of the descending cortico-fugal pathway in speech in noise perception. It can thus be inferred that, the corticofugal pathway helps in fine-tuning the encoding of F0 of regularly occurring signals, which helps in tagging on to voice-pitch of the desired speech signal and eventual stream segregation. The segregation of the desired speech stream from the background streams is important for speech in noise perception and the cortico-fugal system appears to be important for this function.

The context-dependent ALLRs showed a significant relationships with speech in noise perception. The contextual effect on P2 latency and N2 amplitude was related to better speech perception in noise. The Lower SNR-50 was correlated with greater

contextual effect on the ALLR. This correlation however was very low and statistically significant at P2 latency and was just at a borderline significance at N2 amplitude. This suggests that though there exists a relationship between the contextual ALLRs and speech perception in noise, this relationship is rather very small.

The contextual effect in the ALLRs represents the cortico-cortical modulation of the afferent neural input (Costa-Faidella et al., 2011). The suppression of the response to repetitive sound presentation and an enhancement to the non-repetitive sound representation in the present study can be explained by the 'predictive coding model' (Friston, 2005). It suggests that the backward projections carry information from the higher to the lower centres. The backward projections continuously predict the next stimulus based on the predictions of the higher centres in the nervous system and selectively inhibit or facilitate the encoding in the lower centres of the brain (the thalamocortical pathway and the Heschl's gyrus). This predictive coding ability was not different in the younger and the older groups based on the latency and amplitude parameters. But, they differed in the scalp distributions. It can be speculated that this difference in the scalp distributions as a compensatory cortical reorganization due to declining functioning of the speech specific areas in the brain which participate in contextual encoding.

In the light of difference in speech perception in noise and scalp distribution of contextual encoding between the two groups, it can be understood that, though latencies and amplitudes were compensated for with altered scalp distribution in the elder group, the speech perception in noise was not compensated for with this scalp distribution.

The elder group had poorer speech perception in noise in spite of altered scalp distribution of the contextual effect. There can be two possible explanations to this phenomenon; 1) Activation of non-specific regions did not help in speech perception in noise, 2) Activation of non-specific regions resisted further age related decline of speech perception in noise. However, these need further experimental validation.

It suggests the contextual ALLRs in the two groups did not differ significantly but there was a difference in the speech perception in noise.

4.7 The Relationship between speech perception in Noise and CSOAE

The contralateral suppression magnitude showed a significant negative relationship with the SNR-50 value. Lower SNR-50 values suggest greater resistance to the effects of noise on speech perception. Individuals with lower SNR-50 values had greater magnitudes of CSOAE. This finding suggests that CSOAE has an important role in countering the effects of noise on speech perception. This is in consonance with previous studies; Kumar and Vanaja (2004) showed that individuals with dyslexia have poor speech perception and lower CSOAE magnitude. Mukari and Mammat (2008) found lower magnitudes of CSOAE and speech in noise scores in individuals over 50 years.

The relationship between speech perception in noise and CSOAE magnitudes can be attributed to the anti-masking effect of the MOCB (Kawase & Liberman, 1993; Kawase, Delugutte & Liberman, 1993). The anti-masking effect suppresses the incoming signal preferentially, suppresses the response to noise and enhances the signal to noise ratio of the neural input. This top-down modulation by the MOCB is functional online unlike long-term experience dependent plasticity induced modulation of the lower centres.

In the present study, the reduced MOCB functioning revealed by lower CSOAE magnitudes in the elder group is consistent with poorer speech perception in noise ability. Thus, the MOCB functioning can be thought of as a very important mechanism of top-down modulation vital for speech perception in noise.

4.8. Relationship among Physiological Measures of Top-Down Modulation

One of the primary objectives of the study was to verify the inter-relationship among the physiological measures of medial olivocochlear bundle and corticofugal pathways. Results of the present study showed that there was no relationship in the way these two top-down processes modulated speech perception in noise. That is, the functioning of the MOCB is independent of the functioning of the corticofugal pathway. Therefore, to derive the physiological basis of speech perception in noise one needs to evaluate both MOCB and cortico-fugal pathway. Ameen and Sandeep (2011) compared CSOAE among musicians and non-musicians and showed higher efferent suppression in

musicians. The result was attributed to the influence of cortico-fugal modulation on the MOCB. Similarly, Kumar, Hegde and Mayaleela (2010). reported enhancement in the contralateral suppression after short-term training on discrimination of non-native speech sounds which again was attributed to corticofugal modulation of MOCB. Findings of these studies although suggest that cortico-fugal pathway influences MOCB, their role in determining speech perception in noise is independent of each other according to the present findings. They function as two separate entities sharing a common objective of fine tuning the neural responses for better perception.

The results of regression analysis showed that functioning of the MOCB is a better predictor than the functioning of the corticofugal pathway. This means that MOCB plays a more important role in determining speech perception in noise than cortico-fugal pathway. However, in the fitted regression model (equation 3.1) there were few outliers in whom the above said inferences need to be generalized carefully.

Chapter 5

Summary and Conclusions

The primary aim of this research was to find the relative importance of different physiological measures of top-down modulation. Two of the physiological measures were; contralateral suppression of OAEs mediated by MOCB and context dependent encoding of AEPs (ABR & ALLR) mediated by corticofugal pathway. These two physiological measures were compared between younger and elder group of participants with normal hearing sensitivity. The categorisation of the groups based on the age was with the assumption that speech perception in noise would show age related deterioration.

The results of the present study showed that speech perception in noise is related to both MOCB and corticofugal modulation. Of the two, MOCB was found to be playing a more important role in determining speech perception in noise. In addition, it was found that both the physiological measures of top-down modulation do show age related deterioration. Therefore, the age-related deterioration in speech perception in noise reported in the literature and also found in the present study can be attributed partly to the age related changes in the MOCB and the cortico-fugal pathway in normal hearing individuals.

The contextual effect of ABR and ALLR are evidenced in a contrasting way. That is, ABRs get enhanced with repetitive stimulation while ALLRs get suppressed with repetitive stimulation. Although, both these potentials showed contextual effects in the participants of the study, speech perception in noise was found to be related only to the contextual effect of ABR. Therefore, one can infer that the cortico-fugal pathway involved in determining contextual effect of ABR and ALLR are different. Only, the contextual effect of ABR need to be assessed in individuals with poor speech perception in noise. Scalp distribution of ALLR was different in the repetitive vs contextual paradigms. The generators of ALLR in the contextual paradigm are much widely distributed than the generators in the repetitive ALLR. Therefore, one can infer that corticofugal modulation not just fine-tunes the responses but also varies the involved generators.

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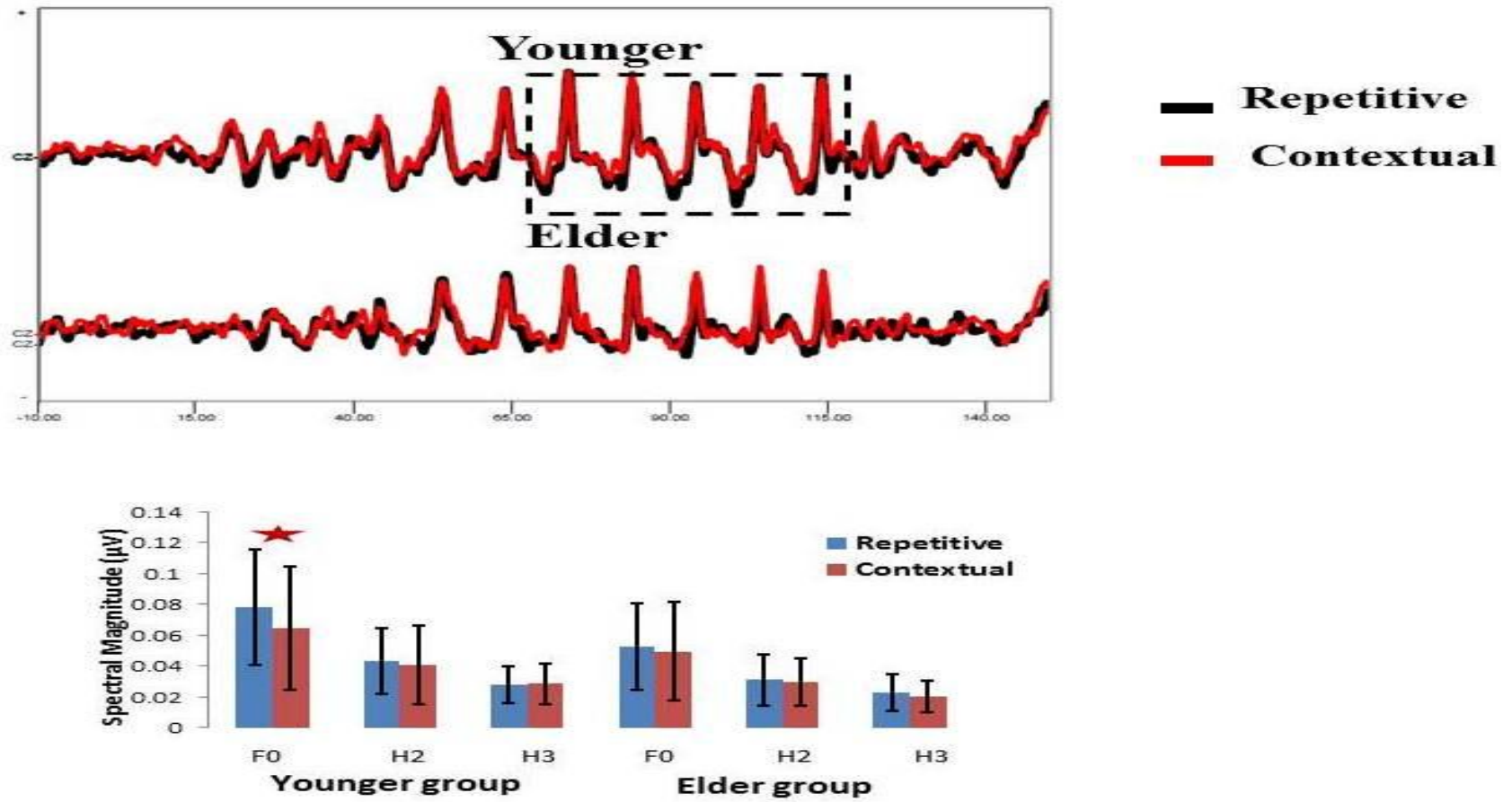
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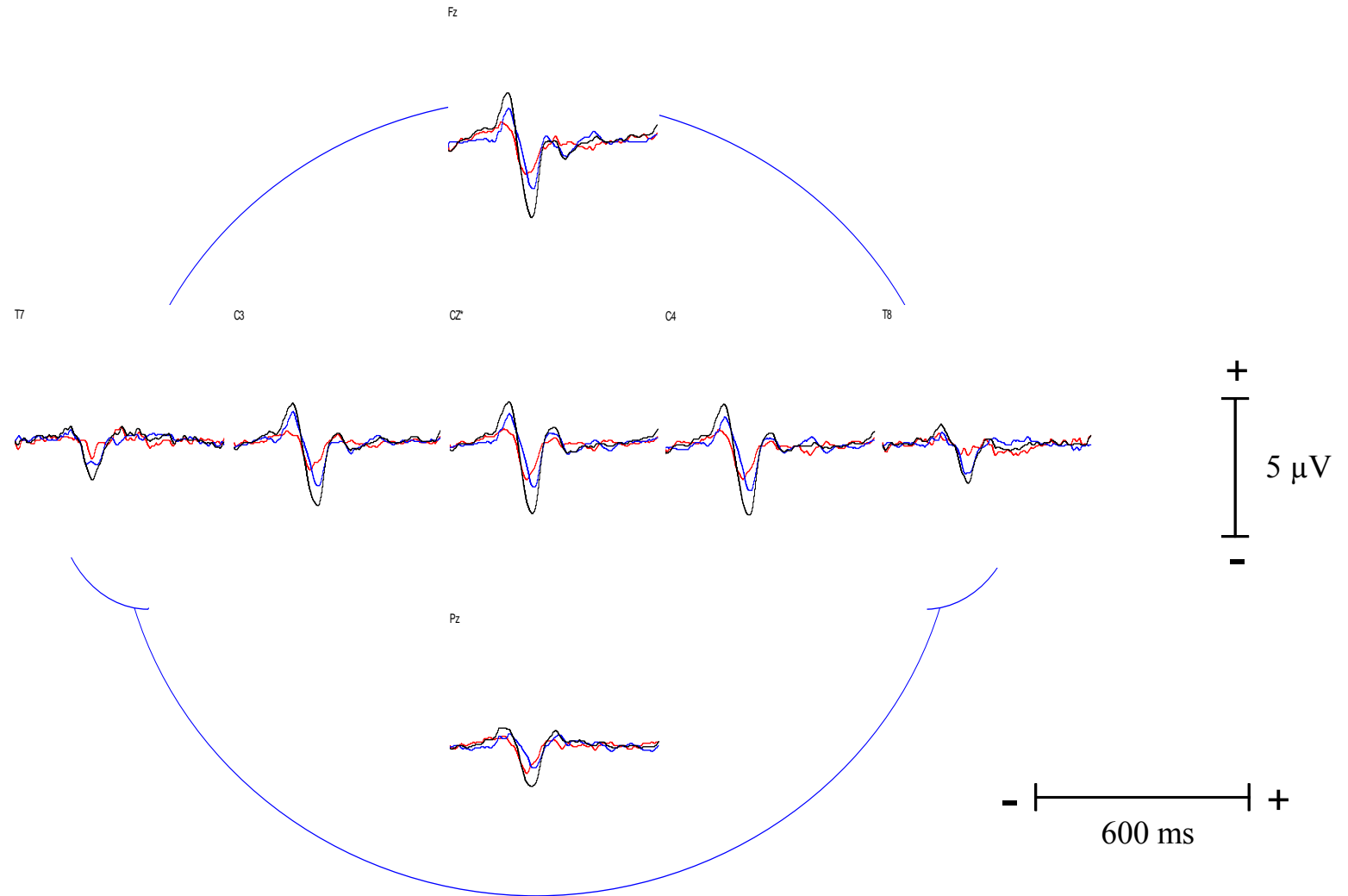
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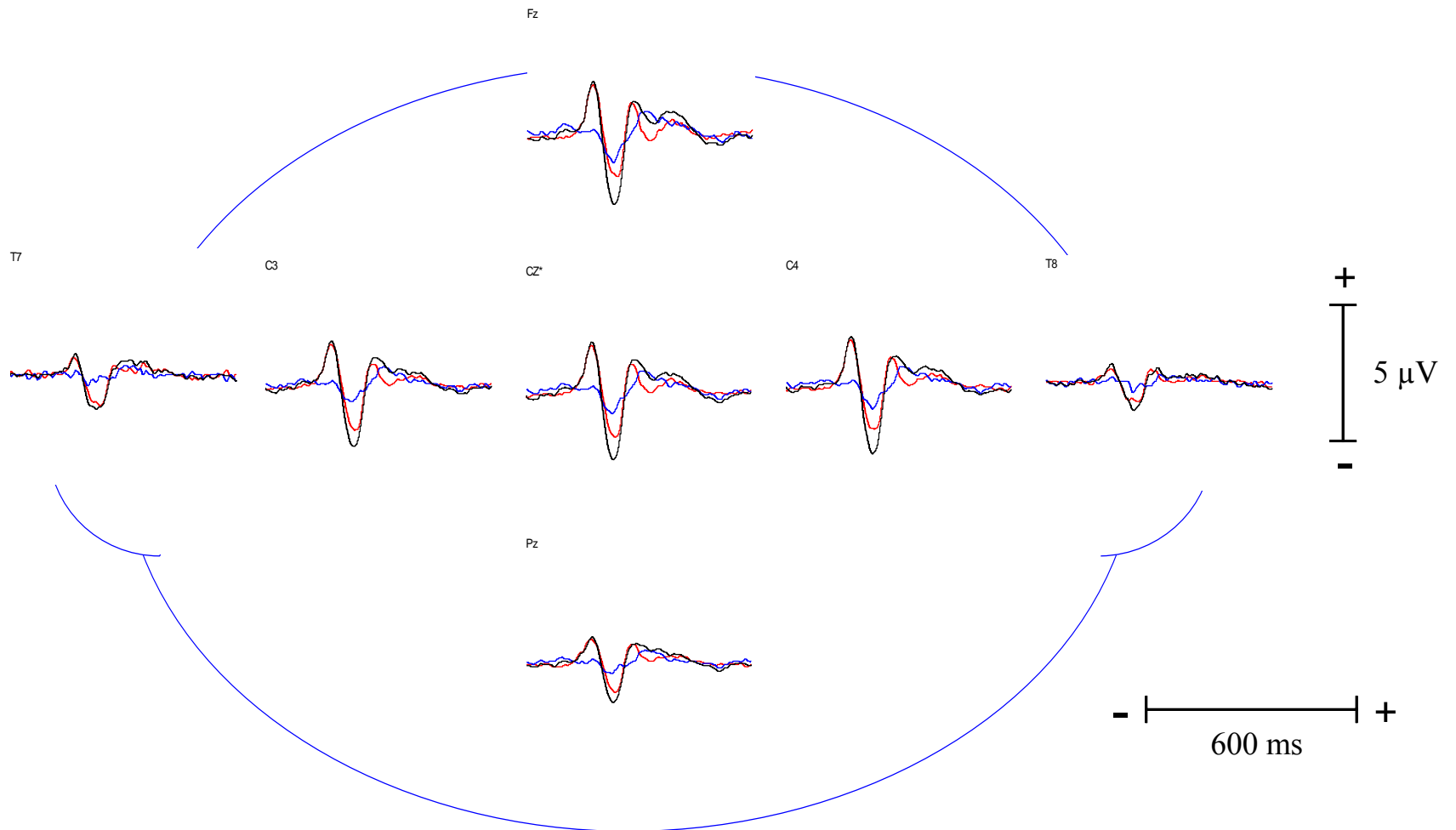
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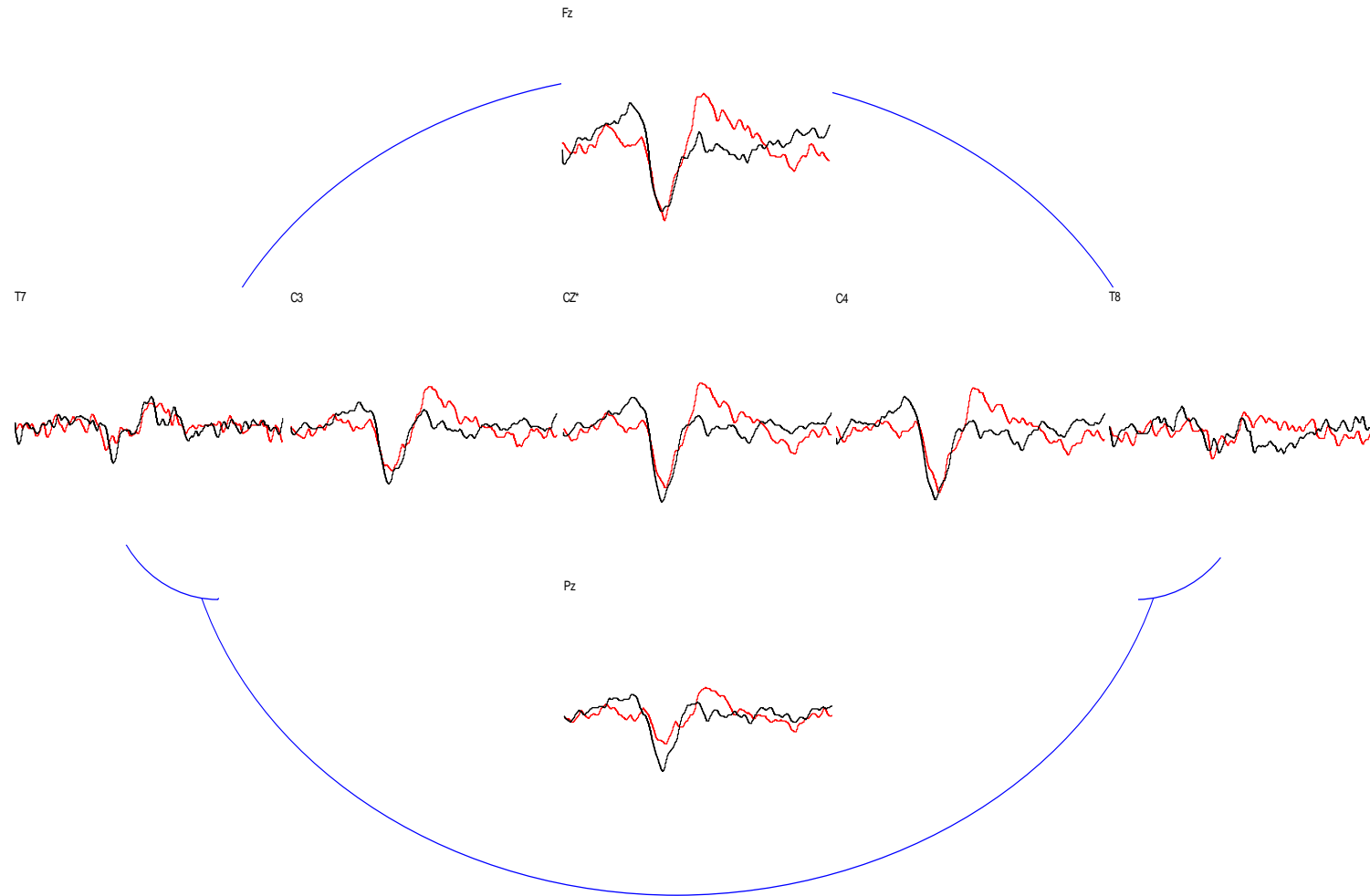
Speech ABR recorded in the repetitive and the contextual paradigm in the two groups



ALLRs in the younger group. The waveform in blue and black were recorded in the repetitive and contextual paradigms respectively. The waveform in black is the difference wave calculated by subtracting waveforms in the repetitive paradigms from the contextual paradigms.



ALLRs in the younger group. The waveform in blue and black were recorded in the repetitive and contextual paradigms respectively. The waveform in black is the difference wave calculated by subtracting waveforms in the repetitive paradigms from the contextual paradigms.



ALLR difference waves in the two groups. The waveform in red and black show difference waves for the elder and younger groups respectively. The difference waves were calculated by subtracting waveforms in the repetitive paradigms from the contextual paradigms.