EFFECT OF TEMPORAL PROCESSING TRAINING IN OLDER ADULTS WITH TEMPORAL PROCESSING DEFICITS

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CERTIFICATE

This is to certify that the thesis entitled ***'Effect of temporal processing training in older adults with temporal processing deficits'*** submitted by Ms. V. Ramya for the degree of Doctor of Philosophy in Audiology to the University of Mysore, Mysuru was carried out at the All India Institute of Speech and Hearing, Mysuru.

Place: Mysuru
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CERTIFICATE

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DECLARATION

I declare that this thesis entitled ***'Effect of temporal processing training in older adults with temporal processing deficits'*** which is submitted herewith for the award of the degree of Doctor of Philosophy in Audiology to the University of Mysore, Mysuru is the result of work carried out by me at the All India Institute of Speech and Hearing, Mysuru, under the guidance of Prof. Asha Yathiraj, Professor of Audiology, All India Institute of Speech and Hearing, Mysuru. I further declare that the results of this work have not been previously submitted for any other degree.

Place: Mysuru **V. Ramya**

Date:

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ABSTRACT

Among the auditory processing problems seen in older adults, temporal processing problems are noted to be common. While considerable work has been done in identifying auditory processing problems in older adults, not much has been done to alleviate these difficulties. Hence, the study aimed to construct training material for temporal resolution problems and check the efficacy of the developed 'Auditory temporal resolution training' (ATRT) programme on older adults with near normal hearing. The study also aimed to establish the effect of the ATRT programme on other auditory processes (temporal processing / patterning, binaural integration, & auditory separation / closure), voicing discrimination as well as auditory memory and sequencing.

Forty-nine participants with normal / near normal hearing, aged between 55 to 74;11 years were initially recruited, out of which 20 were administered the ATRT programme. Among these 20 participants, 13 were 55 to 64;11 years old and 7 were 65 to 74;11 years old. The effect of ATRT was obtained by comparing the performance of the participants on 7 behavioural tests (Gap-In-Noise, Gap Detection, Duration Pattern, Dichotic CV, Speech-Perception-in-Noise, Voicing discrimination word test in Kannada, & Kannada Auditory memory and sequencing) across 4 different evaluations (pre-training evaluations-1 & 2 and post-training evaluations-1 & 2). The effect of ATRT on phoneme errors in the Speech-Perception-in-Noise test in Kannada was also evaluated. Additionally, the effect of the training on an objective measure (Long Latency Response) was also checked across different evaluations (pre-training evaluation-2, post-training evaluations-1 & 2). The two pre-training evaluations were carried out 2 weeks apart and the two post-training evaluations were done one month apart.

No significant difference was observed between the two age groups, as well as between the two pre-training evaluations. However, immediately following training significant improvement in performance was seen in most of the behavioural tests (Gap-In-Noise, Gap Detection, Duration Pattern, Dichotic CV, Speech-Perception-in-Noise, and Auditory memory span) and N1 latency of the LLR. The error analysis also showed a decrease in the total number of errors following training. However, no significant difference was seen in the auditory sequencing span, voicing discrimination, as well as the P2 latency and N1-P2 amplitude of LLR. No significant difference was also observed between the two post-training evaluations for most of the measures that were carried out.

From the findings of the study, it can be inferred that the ATRT programme brought about improvement not only in the auditory process for which training was provided, but also on several other processes and in cortical responses. The effect of training continued to be maintained one month after the cessation of the training. Thus, it can be construed that the developed ATRT programme is useful in older adults having auditory processing problems.

Key Words: Older adults, Auditory Temporal Resolution Training (ATRT), auditory processing, temporal resolution, temporal patterning, binaural integration, auditory separation / closure, voicing discrimination, auditory memory and sequencing, Long Latency Response (LLR).

Chapter 1

INTRODUCTION

"Ageing is not lost youth but a new stage of opportunity and strength."

Betty Friedan (1921-2006).

Ageing has been defined as, "*A persistent decline in the age-specific fitness components of an organism due to internal physiological degeneration*" (Rose, 1990, p. 20). However, there is no consensus regarding the age at which this decline commences, with it varying from 55 to 75 years across studies (Ginzel, Pedersen, Spliid, & Andersen, 1982; Marshall, 1981; Price & Simon, 1984; Strouse, Ashmead, Ohde, & Grantham, 1998).

Hearing loss is known to be a common problem with increasing age. It has been reported that at least 1/3rd the population above the age of 65 years has more than 40 dB hearing loss (World Health Organization, 2015). The most common complaint older adults are reported to have is the inability to understand speech although they are able to hear, which is more pronounced in the presence of background noise (Working Group on Speech Understanding Aging, 1988). Factors other than audibility have been reported to be responsible for this, which include cognitive deficits (van Rooij & Plomp, 1990, 1991, 1992; van Rooij, Plomp, & Orlebeke, 1989) and central auditory processing deficits (Bertoli, Smurzynski, & Probst, 2002; Cox, McCoy, Tun, & Wingfield, 2008; Dubno, Dirks, & Morgan, 1984; Freigang et al., 2011; Gelfand, Hoffman, Waltzman, & Piper, 1980; Jerger, Jerger, Oliver, & Pirozzolo, 1989; Martin & Jerger, 2005; Rodriguez, Disarno, & Hardiman, 1990; Snell & Frisina, 2000; Strouse et al., 1998).

Structural and physiological changes in the auditory system have been found to result in difficulties in auditory perception (Dubno et al., 1984; Gelfand, Piper, & Silman, 1985; Gordon-Salant, 1986; Pedersen, Rosenhall, & Moller, 1991; Prosser, Turrini, & Arslan, 1991; Strouse et al., 1998), and cognition (Martin & Jerger, 2005; van Rooij & Plomp, 1991). With ageing, structural changes have been reported to occur in the external ear (Roeser & Ballachanda, 1997), middle ear structures (Willott, 1991) and the inner ear (Pujol et al., 1991; Soucek & Michaels, 1990). Besides these changes in the peripheral auditory system, alterations have also been seen in the central auditory system (Chisolm, Willott, & Lister, 2003; Frisina, 2001; Stach, Hornsby, Rosenfeld, & DeChicchis, 2009). Close to 3 decades ago, Jerger (1973) and Konkle, Beasley, and Bess (1977) attributed the auditory perceptual difficulties experienced by elderly individuals to the changes in the central auditory nervous system.

It has been well documented that with ageing, older adults face a range of auditory processing difficulties. The various auditory processes that have been found to be affected in older adults include *temporal processing* (Bertoli et al., 2002; Fink, Churan, & Wittmann, 2005; Fitzgibbons, Gordon-Salant, & Friedman, 2006; He, Horwitz, Dubno, & Mills, 1999; John, Hall, & Kreisman, 2012; Pichora-Fuller, Schneider, Benson, Hamstra, & Storzer, 2006; Roberts & Lister, 2004; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Snell, 1997; Snell & Frisina, 2000; Snell, Mapes, Hickman, & Frisina, 2002; Trainor & Trehub, 1989; Vaidyanath & Yathiraj, 2015), *binaural integration* (Cox et al., 2008; Jerger, Alford, Lew, Rivera, & Chmiel, 1995; Jerger, Chmiel, Allen, & Wilson, 1994; Roup, Wiley, & Wilson, 2006), *auditory separation / closure* (Dubno et al., 1984; Gelfand, Piper, & Silman, 1986; Pichora-Fuller, Schneider, & Daneman, 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008) and *binaural interaction* (Pichora-Fuller & Schneider, 1991; Strouse et al., 1998).

The review of literature indicates that temporal processing problems frequently occur in older individuals. More than one type of temporal processing problem has been observed to occur in older individuals. These include deficits in *temporal resolution* (Harris, Eckert, Ahlstrom, & Dubno, 2010; Haubert & Pichora-Fuller, 1999; He et al., 1999; Kumar & Sangamanatha, 2011; Moore, Peters, & Glasberg, 1992; Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 2000; Roberts & Lister, 2004; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002) and *temporal patterning* (Fink et al., 2005; Fitzgibbons & Gordon-Salant, 1998; Fitzgibbons et al., 2006; Kumar & Sangamanatha, 2011; Szymaszek, Szelag, & Sliwowska, 2006; Trainor & Trehub, 1989).

Various tests have been used to evaluate temporal resolution and temporal patterning abilities. A few of the tests used to assess temporal resolution include Random Gap Detection Test developed by Keith (2002), Gap Detection Test developed by Shivaprakash (2003), Gap-In-Noise Test developed by Musiek et al. (2005), and Adaptive Test of Temporal Resolution developed by Lister, Roberts, Shackelford, and Rogers (2006). On the other hand, some of the tests used for assessing temporal patterning include the Pitch pattern test and Duration pattern test developed by Musiek (1994). Additionally, tests of temporal ordering are also included in the Test of Basic Auditory Capabilities (Christopherson & Humes, 1992), a test battery used for assessing auditory processing abilities.

Age has been found to be a factor affecting the performance on these tests. Research using tests of temporal resolution have found gap detection thresholds of older individuals to be poorer than that of young adults. Such findings have noted in studies that have used the Random Gap Detection Test (Owens, Campbell, Liddell, DePlacido, & Wolters, 2007), Gap-In-Noise Test (John et al., 2012; Vaidyanath & Yathiraj, 2015), and Gap Detection Test (Vaidyanath & Yathiraj, 2015).

The research on auditory processing abilities in older adults has mainly focussed on assessing the presence and extent of the problem. Studies reporting about the management of these deficits, especially in older adults, are sparse (Morais, Rocha-Muniz, & Schochat, 2015). The few studies that do provide information on rehabilitation of those with auditory processing problems have focused on children (Bellis, 2003; Katz, Chertoff, & Sawusch, 1984; Maggu & Yathiraj, 2011a, 2011b; Minetti & McCartney, 1978; Priya & Yathiraj, 2007; Vilela, Wertzner, Sanches, Neves-Lobo, & Carvallo, 2012; Yathiraj & Mascarenhas, 2003; Young & Protti-Patterson, 1984). In contrast to the number of studies done on children, research in the management of auditory processing problems in older adults is in its infancy. A recent study by Morais et al. (2015) demonstrated the utility of providing rehabilitation to this population through the use of acoustically controlled auditory training.

Although research on rehabilitation of older adults with auditory processing problems is limited, studies have shown that the brain is plastic even at the later stages of life. This has been demonstrated on bilingual learners (Krizman, Marian, Shook, Skoe, & Kraus, 2012; Luk, Bialystok, Craik, & Grady, 2011), individuals with peripheral hearing loss subsequent to training (Tremblay, Piskosz, & Souza, 2003), and musicians (Parbery-Clark, Anderson, Hittner, & Kraus, 2012).

Thus, the literature provides evidence that older individuals have several auditory processing problems, with temporal processing problems being one of them. However, not much has been done to reduce the impact of this difficulty. Studies have confirmed that the brain continues to be plastic in older adults, highlighting that providing training to this age group would be beneficial.

Need for the study

The presence of auditory processing deficits in older adults with near normal hearing had been well established in the literature. However, the research to alleviate their perceptual problems is sparse.

Need to study auditory processing problems of older adults

The review of literature indicates that older adults have several auditory processing problems. Jerger, Jerger, et al. (1989) and Jerger, Stach, Pruitt, Harper, and Kirby (1989) reported that in older adults, central auditory deficits could occur even in the absence of any significant decline in cognitive abilities and peripheral hearing sensitivity. These findings were also supported by other researchers (Cox et al., 2008; Dubno et al., 1984; Freigang et al., 2011; Gelfand et al., 1980; Jerger, Jerger, et al., 1989; Martin & Jerger, 2005; Rodriguez et al., 1990).

The majority of studies assessing auditory processing deficits in older adults have evaluated isolated auditory processes (Grose, Poth, & Peters, 1994; Jerger et al., 1994;

Newman & Spitzerb, 1983; Pichora-Fuller & Schneider, 1991; Roup et al., 2006; Snell, 1997; Trainor & Trehub, 1989). However, evaluating multiple auditory processes would shed more light on the extent to which each processes is affected in older adults and provide information about the relationship between the auditory processes. Information about the auditory processing tests that are more frequently failed by older individuals would enable selecting the most appropriate test battery when evaluating auditory processes of older adults. Assessing multiple auditory processes would also help pinpointing their processing difficulties, which will assist tailor-made management plans.

Further, research in India in this area is sparse. There is a need to confirm whether perceptual problems of older adults reported in literature are similar in India. This understanding of the auditory processing problems of the older listeners would help improve the quality of services provided to them.

According to the Central Statistics Office Ministry of Statistics and Programme Implementation (2011) of India, the percentage of individuals above the age of 60 years in India is steadily increasing. The total percentage was 7.4% in 2001 and is expected to reach 12.4% of the population by the year 2026. As per the prediction of the United Nations (2013), individuals above the age of 60 is expected to almost double to 21% of the total word population in 2050 from the 12% in 2013. Thus, it is anticipated that the number of older adults who would have age related problems would also increase. This makes it essential that measures be taken to determine ways and means to diminish their problems. One such measure is developing rehabilitative techniques to help counter the auditory processing difficulties of older adults.

Need for behavioural and electrophysiological assessment of auditory processing

Behavioural assessments give a direct measure of the performance of individuals on specific auditory processes. Thus, the functional abilities of individuals with auditory processing problems that can be ascertained through behavioural tests provide an indication of the difficulties faced by the person in a real-life situation. The use of objective measures in conjunction with behavioural tests add to the validity of behavioural tests, as a correlation has been found between the two (Sharma et al., 2006). Further, the use of a combination of electrophysiologic measures along with behavioural measures would give evidence of the underlying physiological changes in the auditory system. The former can also be used to confirm the presence of the behavioural problems. Electrophysiologic responses like LLR have been reported to provide evidence of changes seen after training. Such electrophysiological changes have been noted to occur prior to behavioural changes (Tremblay et al., 2001).

Need for auditory processing training for older adults

Many programmes have been developed to train children having auditory processing deficits and the efficacy of some of these has been assessed (English, Martonik, & Moir, 2003; Katz et al., 1984; Maggu & Yathiraj, 2011a, 2011b; Priya & Yathiraj, 2007; Vilela et al., 2012; Yathiraj & Mascarenhas, 2003). The literature on training programmes for older adults with near normal hearing is sparse. This is despite numerous studies indicating the presence of auditory processing deficits in them.

The aetiology of auditory processing deficits reported in older adults include lesions in the central nervous system, degeneration in the auditory system due to ageing and degenerative diseases, central nervous system damage due to head injury, and cerebrovascular accident (Baran, 2002; Musiek, Gollegly, Lamb, & Lamb, 1990). On the other hand, the aetiology reported in children include lack of or inefficient hemispheric information transfer, imprecise synchrony of neural firing, maturational delay disorganization in the central auditory nervous system, or bilirubin toxicity (Chermak, 1992; Kraus et al., 1996; Moncrieff, Jerger, Wambacq, Greenwald, & Black, 2004; Shapiro, 2003). However, Musiek and Chermak (2006) noted that in most children a clear aetiology is not identified. As the aetiologies are known to be different, the perceptual problems in adults may not be the same as that seen in children making it necessary to have different rehabilitative options for each group. This has also been reported by Baran (2002) who noted that the rehabilitation methods proven to be useful for children with auditory processing difficulties may not be useful for older adults. Hence, new strategies / methods need to developed or the usefulness of the techniques / programs used for children need to be established on adults.

Research on neural plasticity indicate that the brain is plastic even in later stages of life (Krizman et al., 2012; Luk et al., 2011; Parbery-Clark et al., 2012; Tremblay et al., 2001; Tremblay, Piskosz, & Souza, 2002). It can be construed from these studies that providing auditory training to older adults could result in improvement in perception due to plasticity of their brain. There is need to determine if listening training for older adults with auditory processing problems would bring about the desired improvement.

Need for direct remediation training

The rehabilitation options most often used in the past with older individuals have been environmental modifications to improving the quality of signals reaching the individual. Improving of their cognitive and linguistic resources has also been advocated rather than providing direct remediation (Ball et al., 2002). However, direct remediation has been considered highly effective in the rehabilitation of individuals with auditory processing disorder (Bellis, 2003; Katz et al., 1984; Maggu & Yathiraj, 2011a, 2011b; Minetti & McCartney, 1978; Priya & Yathiraj, 2007; Vilela et al., 2012; Yathiraj & Mascarenhas, 2003; Young & Protti-Patterson, 1984). Although the use of environmental modifications or communication strategies has been advocated, proof that they are effective techniques is limited. It has also been shown that training using a direct remedial technique for a particular auditory process results in improvement in other processes (Maggu & Yathiraj, 2011b).

Need for training in temporal processing

Temporal cues have been considered important for categorical perception of consonants. According to Price and Simon (1984), the cues that help in perception of voicing distinction in intervocalic stop consonants is the duration of the preceding vowel and closure duration of the consonant. They found that older listeners required longer duration to make these voicing distinctions compared to the younger listeners. Other temporal cues that help in perception of stop include voice onset time (Lisker & Abramson, 1967). Temporal information like the slope of formant transition is also noted to help in the perception of stop manner of articulation (Liberman, Delattre, Gerstman, & Cooper, 1956; Ohde & Sharf, 1977; Wang, 1959). Thus, temporal cues are considered important for speech perception. Studies assessing temporal processing in older adults have indicated deficits in this area (Newman & Spitzerb, 1983; Snell, 1997; Strouse et al., 1998; Trainor & Trehub, 1989). Temporal processing abilities, specifically gap detection abilities, have been found to have an adverse effect on speech understanding abilities, especially in the presence of noise (Phillips et al., 2000; Snell & Frisina, 2000). There is a need to ascertain whether providing training to improve temporal processing abilities will also help in the improvement of other auditory processes and speech perception. This would have a positive influence on the communication skill, which in turn may positively influence the life style of the individual.

Need to use nonverbal stimuli for training

Nonverbal stimuli have the advantage of being applicable universally across individuals speaking different languages. Thus, irrespective of the language spoken by an individual, the training material could remain the same. Studies have shown that training using nonverbal stimuli resulted in improvement in perception of speech signals also (Maggu & Yathiraj, 2011b; Vanaja & Sandeep, 2004). These studies provided training for temporal patterning using nonverbal tonal stimuli of 250, 500, 1000 and 2000 Hz (Maggu & Yathiraj, 2011b) as well as for discrimination in duration, frequency and intensity using tones of different frequency, intensity and duration (Vanaja & Sandeep, 2004). Thus, there is a need to see if similar improvements can be seen with the use of temporal resolution training.

From the literature, it is clear that auditory processing problems exist in older adults with near normal hearing. However, the research on rehabilitation for these individuals is minimal. Hence, there is a need to develop a training programme for these older individuals and validating its usefulness.

Aim

The study aimed to determine the efficacy of ‘Auditory temporal resolution training’ (ATRT) in older adults with near normal hearing and establish its effect on other central auditory processes (temporal processing / patterning, binaural integration, & auditory separation / closure), voicing discrimination, auditory memory and sequencing as well as electrophysiological responses.

Objectives

The objectives of the study are as follows:

- Study the difference in performance between two groups of older adults on temporal processing (Gap-In-Noise test, Gap Detection Test & Duration Pattern Test), binaural integration (Dichotic CV test), auditory separation / closure (Speech Perception in Noise test in Kannada), voicing discrimination (Voicing Discrimination Word Test) as well as auditory memory and sequencing (Kannada Auditory Memory and Sequencing Test),
- Study the effect of ATRT on temporal processing (GIN, GDT & DPT), binaural integration (DCV), auditory separation / closure (SPIN-K), voicing discrimination (VDWT) as well as auditory memory and sequencing (KAMST),
- Study the effect of ATRT 4 weeks after the cessation of training, on temporal processing, binaural integration and auditory separation / closure, voicing discrimination as well as auditory memory and sequencing,
- Study the effect of ATRT programme on perception of voicing in minimal word-pairs that differ only in voicing,

- Assess the phonemic error patterns in speech perception in the presence of noise in older adults, before and after ATRT programme, and
- Study the effect of ATRT on the latency and amplitude of speech evoked auditory cortical responses.

Hypotheses

The null hypothesis formed to investigate the above objectives are as follows:

Hypothesis 1:

There is no significant difference between the performance of the two age groups on auditory processes [temporal resolution (2 tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing.

Hypothesis 2:

There is no significant difference in performance on auditory processes [temporal resolution (2 tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing without intervention / training.

Hypothesis 3:

Temporal resolution training has no significant effect on performance in the following:

a. Tests of temporal resolution (GIN & GDT),
b. Test of Temporal ordering (Duration Pattern Test),
c. Test of Binaural integration (Dichotic CV test),

d. Test of Auditory separation / closure (Speech-Perception-in-Noise test in Kannada),
e. Voicing discrimination word test in Kannada,
f. Test of auditory memory and sequencing (Kannada auditory memory and sequencing test),
g. Phoneme error pattern in the presence of noise and
h. Speech evoked cortical responses (LLR).

Hypothesis 4:

Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in the following:

a. Tests of temporal resolution (GIN & GDT),
b. Test of Temporal ordering (Duration Pattern Test),
c. Test of Binaural integration (Dichotic CV test),
d. Test of Auditory separation / closure (Speech-Perception-in-Noise test in Kannada),
e. Voicing discrimination word test in Kannada,
f. Test of auditory memory and sequencing (Kannada auditory memory and sequencing test),
g. Phoneme error pattern in the presence of noise and
h. Speech evoked cortical responses (LLR).

Prior to studying the above objectives / hypotheses, a review of literature was carried out on the auditory processing problems of older adults. Additionally, the remediation techniques used in individuals with auditory processing problems was also reviewed. This was done in order to determine the most appropriate method to carry out the research.

Chapter 2

REVIEW OF LITERATURE

Decline in functional abilities with advance in age has been well established. Auditory processing abilities is one such functional ability that has been noted to decline with age (Bertoli et al., 2002; Dubno et al., 1984; Fitzgibbons & Gordon-Salant, 1998; Jerger et al., 1995; Pichora-Fuller & Schneider, 1991; Prosser et al., 1991; Roup et al., 2006; Schneider et al., 1994; Snell, 1997; Strouse et al., 1998). A variety of auditory processes has been shown to be adversely affected with advance in age. These include deficits in *temporal resolution and temporal patterning* (Bertoli et al., 2002; Fink et al., 2005; Fitzgibbons & Gordon-Salant, 1998; Fitzgibbons et al., 2006; Harris et al., 2010; Haubert & Pichora-Fuller, 1999; He et al., 1999; John et al., 2012; Kumar & Sangamanatha, 2011; Moore et al., 1992; Phillips et al., 2000; Pichora-Fuller et al., 2006; Roberts & Lister, 2004; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002; Trainor & Trehub, 1989; Vaidyanath & Yathiraj, 2015), *binaural integration* (Gelfand et al., 1980; Jerger et al., 1995; Jerger et al., 1994; Roup et al., 2006), *auditory separation / closure* (Anderson, Parbery-Clark, Yi, & Kraus, 2011; Cox et al., 2008; Dubno et al., 1984; Frisina & Frisina, 1997; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008; Wong, Ettlinger, Sheppard, Gunasekera, & Dhar, 2010), and *binaural interaction* (Grose et al., 1994; Pichora-Fuller & Schneider, 1991; Strouse et al., 1998). Both behavioural and electrophysiological measures have been used to confirm the presence of these deficits. While there are several studies on the evaluation of auditory processing deficits in older individuals, research on rehabilitation of these individuals is sparse. The review provided below includes information regarding the effect of ageing on different auditory processes and the rehabilitation options utilised on older individuals.

2.1 Effect of age on auditory processes

The effects of age on various auditory processes have been studied. The auditory processes reviewed here include temporal processing, binaural integration, and auditory separation closure.

2.1.1 Effect of age on temporal processing.

Temporal processing has been considered to be essential for the perception of speech (Gordon-Salant & Fitzgibbons, 1993; Liégeois-Chauvel, de Graaf, Laguitton, & Chauvel, 1999; Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995) especially for the perception voicing (Lisker & Abramson, 1967; Summerfield, 1982; Tyler, Summerfield, Wood, & Fernandes, 1982) and for the perception of music (Bellis, 2003; Hirsh, 1959). It is also found to be important for sound localization and perception of signals in the presence of noise (Phillips et al., 2000; Snell & Frisina, 2000; Snell et al., 2002; Strouse et al., 1998). In literature, temporal processing has been noted to encompass a variety of time-based aspects. According to the definition of (C)APD by American Speech-Language-Hearing Association (2005), temporal aspects of audition includes temporal integration, temporal discrimination (temporal gap detection), temporal ordering and temporal masking. Studies related to different aspects of temporal processing in older adults are reviewed below.

2.1.1.1 Effect of age on temporal resolution.

Temporal resolution is commonly assessed using a gap detection method. "Gap detection procedure measures the ability of the listeners to detect the presence of brief temporal interval between successive signals, usually discrete noise or tone bursts" (Fitzgibbons & Gordon-Salant, 1996, p. 184). Researchers have evaluated gap detection abilities in older adults using a variety of stimuli and procedures (Harris et al., 2010; Haubert & Pichora-Fuller, 1999; He et al., 1999; John et al., 2012; Moore et al., 1992; Phillips et al., 2000; Pichora-Fuller et al., 2006; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002; Vaidyanath & Yathiraj, 2015).

Moore et al. (1992) used pure-tones having frequencies from 100 to 2000 Hz to assess gap detection abilities. They studied gap detection thresholds in 2 groups of older individuals, one group with presbycusic hearing loss, aged between 62 to 86 years and another with near normal hearing till 2 kHz, aged between 62 to 83 years. Using a three-alternate forced choice procedure to obtain gap detection threshold in 400 ms sinusoidal markers, they found that the gap thresholds improved with increase in intensity and reached an asymptote from 25 dB to 70 dB SPL. However, at 85 dB SPL, the highest intensity level that was used in their study, a few subjects showed slight deterioration in performance. For each participant, interpolating the responses, they determined the level where gap detection was 50% higher than the mean value for the higher intensity level used by them for each frequency. This was found to be similar to young adults for the group with normal hearing while it was lower in the group with hearing loss. This was attributed to the presence of loudness recruitment in these older listeners. The gap detection thresholds were reported to be similar for the two older groups and significantly higher when compared to the young normal group. Although the researchers reported of higher gap detection thresholds in the older adults, they observed that a large number of these individuals showed gap detection thresholds within the normal range. The diversity in findings was attributed to the lesser cognitive demand required for gap detection in sinusoids compared to other tasks like temporal order judgement for assessing temporal processing abilities.

The effect of age on temporal resolution using Gaussian-enveloped 2 kHz tone-bursts and a two-alternate forced choice procedure was studied by Schneider et al. (1994). The mean gap detection thresholds of older adults (mean age of 69.2 years, SD of 4.8 years) with hearing thresholds ≤ 25 dB HL, were found to be 6.2 ms and 6.5 ms in the right and left ear respectively. This was significantly higher than that of younger group (mean age of 23 years, SD of 1.5 years) studied by them who obtained gap detection thresholds of 3.8 ms and 3.5 ms in the right and left ear respectively. Additionally, a higher variability in the gap detection thresholds in the older adults was also reported. They however failed to obtain any significant correlation between gap detection thresholds of the two groups with the audiometric thresholds at 2 kHz.

Snell (1997) used a temporal gap detection paradigm with low-pass noise bursts at 6 kHz and 1 kHz to compare young adults aged between 17 and 40 years (mean age of 25.6 years) and older adults aged between 64 and 77 years (mean age of 69.6 years) with matched hearing thresholds. Gap detection was assessed in three different conditions (no background noise, continuous noise floor of white noise at 45 dB SPL, & high-pass filtered noise with cut-off frequencies of 6 and 12 kHz with the continuous white noise). It was found that age and the frequency of the stimuli affected performance. The young adult group obtained smaller gap thresholds than the elderly listeners and these thresholds were smaller for the 6 kHz stimuli than the 1 kHz stimuli. Further, the gap thresholds were significantly higher at 80 dB SPL when compared to 70 dB SPL for 6 kHz stimuli. The addition of the noise floor and the high-pass filtered noise had a detrimental effect on gap threshold for 1 and 6 kHz stimuli. Additionally, it was reported that the pattern of response of the young adult and the older adult groups were similar for the various stimuli conditions, though the older adults were more sensitive to the presence of the background signal. The authors concluded that the results indicated poorer performance of older adults on a temporal resolution task.

To study gap detection thresholds as well as plot the psychometric functions of gap detection, He et al. (1999) evaluated 7 young adults (mean age of 31.9 years, SD of 8.1 years) and 6 older adults (mean age of 70.5 years, SD of 5.4 years). They found that increasing the duration of noise bursts improved gap detection thresholds, especially for the older adults. However, this improvement in gap detection thresholds was not significantly different from the improvements seen in young adults. The slope of the psychometric function was also reported to be similar in the two age groups. The uncertainty in the location of the gap occurring at a fixed interval or occurring randomly across the noise bursts did not result in significant differences in gap detection thresholds between the two groups. However, a significant difference in the slope of the psychometric function of the two groups was observed. They also found that the location of the gap within the noise burst had significant effect on gap detection threshold, especially for the older adult group. These results were attributed to an adaptation seen in the eighth cranial nerve.

In addition to the effects of age on temporal resolution, researchers have also tried to find the relation between temporal resolution abilities and speech perception, especially in the presence of noise. Haubert and Pichora-Fuller (1999) examined the relationship between gap detection thresholds and speech perception abilities for VCV words in 8 young listeners (20 to 30 years) and 8 older listeners (68 to 74 years) with normal hearing sensitivity. The VCV word continuums presented in quiet and in presence of noise were such that a progressive increase in gap duration changed the perception from one token of the continuum to the other (eg. cash to catch). These continuums were presented at slow and fast rates of speech. They observed that the older listeners required longer gap duration to distinguish the two words in a continuum at both rates. They also found that the gap detection thresholds of the older individuals were significantly longer compared to that of younger adults, especially for the shortest duration markers. However, the authors reported that a significant correlation was not found between the gap detection thresholds and word identification scores. They reported that the longer gap detection thresholds observed in the older listeners compared to the young adults could be due to the longer duration required for the auditory nerves to recover from adaptation after the presentation of the leading marker and to fire for the trailing marker. The duration to detect the presence of gaps was considered essential in the identification of stop consonants and in turn the word identification.

Snell and Frisina (2000) evaluated the effect of age and hearing thresholds in a group of 40 young adults (aged 17 to 40 years, with mean of 26.4 years) and 40 older adults (aged 61 to 82 years, with mean of 68.3 years). They assessed gap detection abilities for noise bursts having low-pass filter cut-off frequencies of 1 and 6 kHz in three background conditions. The background noise included no background noise, continuous white noise, and high frequency masker. They reported a significant effect of age and background conditions on gap detection thresholds. The younger group was reported to have significantly smaller gap detection thresholds compared to the older adult group. However, no significant correlation was obtained between the hearing threshold and gap detection thresholds as well as gap detection threshold and age for the older adult group. This was considered to have occurred since all the participants had normal hearing thresholds. In contrast to the findings of the older adult group, a significant correlation between age and gap thresholds for the 1 kHz noise burst was reported for the younger age group. Further, they found a significant correlation between the gap detection thresholds with noise burst carrier low pass filtered at 6 kHz and spondee-in-babble thresholds only for the young adult group. Hence, they concluded that temporal resolution abilities could partly explain the variability in the spondee-in-babble thresholds, but only in the younger group.

The relation between poor speech understanding abilities and deficits in temporal and frequency resolution was examined by Phillips et al. (2000). They measured gap detection thresholds to evaluate the temporal resolution abilities and critical ratios to evaluate frequency resolution abilities in three groups with 12 participants in each. The three groups included elderly normal hearing listeners in age range of 60 to 78 years (mean age of 70 years), elderly listeners with hearing impairment having good word-recognition scores in the age range of 64 to 79 years (mean age of 72 years), and elderly listeners with hearing impairment having poor word-recognition scores in age range of 60 to 80 years (mean age of 73 years). Syllable recognition in quiet and noise was also assessed using a nonsense syllable test. They reported that the older adult group with normal hearing showed better gap detection thresholds compared to the other two groups. A significant difference was not reported between the two groups with hearing loss. It was reported that though temporal resolution abilities was not able to distinguish between the two groups with hearing loss, it was able to account for a small portion of the variance in speech recognition performance in noise when all the three groups were combined. Based on the findings of the study the authors suggested that deficits in temporal resolution abilities contributed to difficulties in syllable recognition in noise for some older listeners. A similar conclusion was drawn by Snell and Frisina (2000) in an earlier study.

The relationship between temporal resolution and speech perception in the presence of noise was further supported in a study by Snell et al. (2002). They evaluated the link between word recognition in the presence of noise and the ability to detect gaps embedded in noise bursts in older adults aged 55 to 88 years with normal hearing or mild hearing loss (mean age of 68.7 years) as well as young adults aged 18 to 52 years (mean age of 31.4 years). Temporal resolution abilities were evaluated using a three-interval forced choice procedure with gaps embedded close to the onset of noise bursts having an upper cut-off frequency of 6 kHz. Word recognition abilities were assessed using NU-6 word lists in the presence of four-talker babble. The authors reported a significant effect of age on both gap detection thresholds and word recognition performance. They also found that gap detection threshold was a significant covariate contributing to word recognition in the presence of babble while high frequency and pure-tone average were not.

The studies mentioned earlier used gaps embedded in pure-tones or noise bursts (also referred to as markers) that were spectrally constant before and after the gap (Haubert & Pichora-Fuller, 1999; Phillips et al., 2000; Snell & Frisina, 2000; Snell et al., 2002). According to Phillips, Taylor, Hall, Carr, and Mossop (1997) this requires the detection of discontinuity in the stimuli by the auditory neurons within a perceptual channel and hence was referred to as 'within channel processing'. Unlike these studies, markers having different spectral and duration dimensions before and after the gaps have been utilised. For a gap embedded between spectrally different markers, a comparison of the firing between different perceptual channels was considered to be performed and hence was referred to as 'between channel processing'.

Using spectrally dissimilar markers, Pichora-Fuller et al. (2006) compared temporal resolution abilities of 16 young aged 21 to 35 years (mean age of 24 years) and older adults with near normal hearing aged 67 to 82 years (mean age of 75 years). They used both speech and non-speech stimuli that were either similar or different in terms of frequency and duration. They reported that the gap detection thresholds of the older adult group were larger compared to that of the younger adult group in all the conditions they studied. Additionally, the gap detection thresholds were found to be poorer for speech stimuli compared to non-speech stimuli with spectrally similar markers. They also reported poorer gap detection thresholds for short duration markers compared to the longer duration markers of the speech stimuli. It was observed that the gap detection thresholds obtained in the asymmetrical conditions were about 4 to 50 times larger than those obtained in the similar symmetrical conditions. Further, they observed that the gap detection for short duration speech markers yielded the smallest age difference. The degree of periodicity of the markers was considered to influence the gap detection in speech markers than non-speech markers. They also reported other possible reasons for the poorer performance for non-speech stimuli in spectrally asymmetrical conditions. These included the spectral overlap of the markers, the energy distribution across the frequencies, the additional acoustic cues available for speech stimuli compared to non-speech stimuli and the use of phonological knowledge when processing speech signals. Based on their findings, the authors suggested that gap detection in more complex and spectrally asymmetrical markers required more central processing.

Yet another variable that has been considered to affect gap detection thresholds in older adults is processing speed and workload. Harris et al. (2010) studied the effect of these parameters using modified version of NASA TLX self-report questionnaire to assess workload and Purdue Pegboard to assess processing speed. They compared gap detection thresholds of 10 younger adults (mean age of 25.1 years, SD of 2.42 years) and 11 older adults (mean age of 69.82 years, SD of 6.95 years) using two types of gaps. The gaps were either present at fixed intervals (5%, 50%, or 95% of the total duration of the noise burst) or randomly varied in location. The gap detection thresholds of the older adults were reported to be poorer than that of the younger adult group in most of the conditions. The gap detection thresholds for the random conditions were significantly higher than that obtained in the fixed condition for gaps located at 5% and 95% of the total noise burst duration but not when placed at 50% of the total noise burst duration. The authors also reported that older adults rated the tasks to be more mentally demanding when compared to the younger adult. A correlation between gap detection thresholds and processing speed was not obtained in the fixed condition whereas a negative correlation was reported in the random condition. The slower processing speed was associated with longer gap detection thresholds. Based on these findings they concluded that cognitive processing and processing speed also contributed to the age-related differences observed in gap detection thresholds.

In addition to the various psychoacoustical procedures used to study the effect of age on temporal resolution abilities, researchers have also used different diagnostic tests to assess temporal resolution. John et al. (2012) used Gap-In-Noise test developed by Musiek et al. (2005) to compare the performance of 50 young adults having normal hearing (mean age of 25.6 years, SD of 3.7 years) with that of 76 older adults having hearing loss (mean age of 65.7 years, SD of 8.7 years) and 28 older adults without hearing loss (mean age of 57.3 years, SD of 5.3 years). They found that the approximate gap thresholds obtained by the three participant groups differed significantly. The young normal hearing group was reported to perform better than the older adult group with normal hearing, who in turn had better gap detection thresholds than the older adult group with hearing loss. A negative correlation was obtained between the articulation index that was calculated and approximate gap thresholds. Further, a positive correlation was noted between age and approximate gap threshold in individuals with near normal hearing sensitivity. They reported a 0.55 ms increase in the GIN approximate gap threshold with every 10 years of age. The highest variance in approximate gap threshold was reported in the older adults with hearing loss and the least variance was seen in the young adult with normal hearing. The slopes of the psychometric functions obtained were reported to indicate a decrease in the performance with both age and hearing loss.

The performance of a group of older adults aged between 55 to 70 years (mean age of 60.39 years) with normal hearing till 2 kHz was compared on two tests of temporal resolution by Vaidyanath and Yathiraj (2015). The two tests included GIN developed by Musiek et al. (2005) and GDT developed by Shivaprakash (2003). It was noted that the gap detection thresholds obtained using the two tests differed significantly from each other. The thresholds obtained on GIN were poorer than that obtained on GDT. The poorer performance on GIN compared to GDT was attributed to the difference in the design of the test and the procedure used for obtaining the responses. The randomness in the presentation of the gap and the uncertainty in the location of the gap were also reported as reasons for poor performance on GIN. Further, it was observed that the performance of the older adults on both the tests was poorer than the norms given by the developers of the tests on young adults.

Another technique used to measure temporal resolution abilities in older adults is the detection of periodic fluctuations in sinusoidally amplitude-modulated noise. Takahashi and Bacon (1992) used such a technique to measure temporal resolution abilities in older adults in three age groups (50, 60, & 70 years). They reported that the temporal modulation transfer functions obtained in the older adults was similar to that of younger adults except in the higher frequencies. However, the mean time constants were longer for the older adult group compared to the younger adults, though it was not found to be significant.

In a later study, He, Mills, Ahlstrom, and Dubno (2008) measured temporal modulation transfer functions for signals with carrier frequencies of 500 and 4000 Hz. The modulation frequencies used for 500 Hz carrier signal were 5, 40, 80, 100, 200, and

250 Hz. In addition to these modulation frequencies, 500 and 1000 Hz modulation frequencies were used for the 4000 Hz carrier signal. They reported a significant effect of age on temporal modulation transfer functions based on a comparison of 8 young adults (mean age of 20.5 years, age range of 18 to 26 years) and 8 older adults (mean age of 70.6 years, age range of 60 to 80 years) with normal hearing. Age-related differences were observed to become more with increase in modulation frequency. In the older adults, they observed a linear increase in amplitude modulation detection thresholds with increase in modulation frequency from 5 to 100 Hz. A significant difference was reported for most of the frequencies when the two groups were compared at each of the modulations frequencies. The authors suggested that this difference could indicate a difference in the temporal information available in lower and higher carrier frequencies and the way this information was used by the two groups.

Strouse et al. (1998) evaluated the effect of ageing on processing of temporal information through monaural input as well as through binaural input. Monaural processing was evaluated using a gap detection test and binaural processing was assessed using interaural time difference thresholds. Their 12 young listeners (aged 20 to 30 years, mean age of 26.1 years) were found to perform better that their 12 gender and hearing sensitivity matched older listeners (aged 65 to 75 years, mean age of 70.9 years) on a gap detection task at three sound levels (4, 8, & 16 dB). The difference in performance was more at the lowest intensity levels. These results were noted to be in congruence with those reported by Moore et al. (1992) and Snell (1997) and Schneider et al. (1994). Further, similar to what was observed for the gap detection task, for the interaural time difference task, Strouse et al. found the older adults to perform significantly poorer than the younger adults. Additionally, in the older adults a reduction in the sound level had negative effects on the use of interaural time delay cues for lateralizing sound sources.

Roberts and Lister (2004) studied effect of age and hearing loss on gap detection and fusion performance using monotic, diotic and dichotic stimuli. They compared the performances across the two tasks in three groups of listeners comprising of young normal hearing adults (mean age = 24.5 years, SD of 4 years), older adults with normal hearing (mean age = 60.5 years, SD of 7.5 years) and older adults with hearing impairment (mean age = 67.1 years, SD of 6.7 years). Gap detection thresholds and lag-burst thresholds were measured in monotic, diotic and dichotic conditions. They observed that the gap detection thresholds of the young adults were better compared to the two older adult groups. However, a significant difference between the groups was not found for monotic and diotic gap detection thresholds. Poorer performance in dichotic gap detection thresholds was reported in the older adult group with normal hearing compared to the older adults with hearing impairment and young adults with normal hearing. A significant difference was also reported for the lag-burst duration between the three groups.

Kumar and Sangamanatha (2011) evaluated binaural temporal resolution abilities of 176 participants across six age groups (20 to 30, 31 to 40, 41 to 50, 51 to 60, 61 to 70 and 71 to 85 years). This was evaluated in addition to binaural temporal sequencing, duration discrimination and modulation detection. They assessed the ability to detect gaps embedded in a broadband noise of 750 ms. The authors found that the age groups above 40 years (41 to 50; 51 to 60; 61 to 70 & 71 to 85 years) differed significantly from the two younger age groups (20 to 30 & 31 to 40 years) on gap detection thresholds. From the results, the authors concluded that temporal processes, including temporal resolution, tended to deteriorate by the fourth decade of life.

In addition to a psychoacoustic procedure for assessing temporal resolution abilities, Bertoli et al. (2002) evaluated mismatch negativity (MMN) to determine the relationship between the two. They obtained behavioural gap detection thresholds and MMN responses for a 1 kHz pure-tone signal in 10 older adults aged between 62 to 79 years (mean age of 72 years). The findings of the older adults were compared with that of young adults aged between 19 to 30 years (mean age of 26 years) studied by Bertoli, Heimberg, Smurzynski, and Probst (2001). A poorer mean gap detection threshold was found in the older adults compared to the younger adults on the psychoacoustic test as well as on MMN. Both the groups had higher MMN thresholds compare to behavioural thresholds. Age related differences in the gap detection thresholds were reported only for MMN and not for the behavioural tests. From these findings, they concluded that temporal resolution was reduced in the older adult group at the pre-attentive level of auditory processing.

The review on the temporal resolution abilities indicates that this auditory process declines with age. Detection of small duration gaps embedded in a variety of stimulus types have been reported to be difficult for older adults compared to young adults. This difficulty has been noted by researchers using different behavioural techniques to evaluate temporal resolution (detection of gaps embedded in sinusoids, broadband noise, low-pass filtered noise, gaps occurring randomly or at a fixed location in the stimuli as well as tests like GIN & GDT). Further, the difficulties reported in the behavioural studies have also been supported by evidences from electrophysiological studies.

2.1.1.2 Effect of age on temporal ordering.

Temporal ordering, the ability to perceive sequence of sounds, has been reported to be important in perception of speech and music (Rawool, 2013). Several studies have been conducted in older adults to determine their abilities to identify the correct order of sound sequences (Fink et al., 2005; Fitzgibbons & Gordon-Salant, 1998; Fitzgibbons et al., 2006; Kumar & Sangamanatha, 2011; Szymaszek et al., 2006; Trainor & Trehub, 1989).

Trainor and Trehub (1989) compared temporal sequencing abilities in elderly listeners aged between 63 to 77 years (mean age of 69 years) with the performance of young adults aged between 18 to 25 years (mean age of 21 years). To assess auditory stream segregation, they tested the participants using two test sequences that sounded identical when played at rapid speeds and were distinguishable when played at slower speeds. They reported that the elderly listeners performed poorer than the younger listeners on all 8 speeds used that varied in onset-to-onset time of successive tone of presentation (100, 160, 220, 280, 340, 400, 460, & 520 ms). Further, the performance did not improve at slower speeds. The authors attributed the poor performance of the elderly group to the complexity of the identification response. Hence, they simplified the response paradigm to a same / different judgement and rated the confidence of judgement on a seven point rating scale. As the performance of the elderly group remained poorer than the younger group even after simplification of the task, the difficulty was ascribed to age-related deficits in temporal order discrimination. Further, to establish whether practice could have influenced the performance, the authors tested four of the elderly and younger listeners over five sessions. The first three sessions served as practice sessions and last two were used to evaluate their performance. It was found that the performance improved with practice, but the pattern of response remained the same. The poor performance of the elderly group was considered to be on account of their uncertainty in the prediction of the stimuli, the non-tonal structure of the stimuli sequences and effect of other central auditory mechanisms.

Similar to the study by Trainor and Trehub (1989), Fitzgibbons and Gordon-Salant (1998) studied the effect of ageing on temporal ordering abilities using discrimination and identification tasks with stimuli that varied in complexity. They evaluated four groups, two young adult groups as well as two older adult groups. The young adult group with normal hearing was aged between 20 to 40 years and the other young adult group with hearing loss was aged between 18 to 44 years. The two older adult groups with normal hearing and other with mild-moderate sloping hearing loss were aged between 65 to 76 years. The performances of the groups on discrimination of temporal order were compared on three stimulus conditions that increased in complexity from unidirectional frequency shifts, bidirectional frequency shifts, to random condition. For the temporal order identification task, the stimuli from the random frequency shift condition were used with tonal duration of 750, 500, 250, and 100 ms. They observed a significant effect of age and condition on the mean tonal duration thresholds with the younger adult group performing better than the two older adult groups. The performance on the unidirectional frequency shift condition was better compared to that reported for bidirectional frequency shift and random condition. However, they reported no significant effect of hearing loss on these thresholds in all three conditions. On the temporal order identification task, the authors failed to obtain significant effects of age and hearing loss on the performance. On the other hand, a significant correlation was reported between the duration thresholds for order discrimination and percent correct order identification scores for the random frequency shift condition for 100 ms stimuli. From the findings of the study, it was concluded that the stimulus durations required for order identification was larger than that required for order discrimination and the age related differences observed were dependent on the stimulus complexity.

Comparing different psychoacoustic methods used for obtaining temporal order thresholds, Fink et al. (2005) compared thresholds obtained using staircase technique and maximum likelihood based algorithm, ‘Yet another adaptive procedure’, for clicks and pure-tone signals. The temporal order thresholds obtained using each of these methods from older adult group (aged 55 to 70 years, mean age of 61.7 years) was compared with that of younger adults (aged 20 to 35 years, mean age of 25 years). They found no significant difference between the thresholds obtained using staircase technique and ‘Yet another adaptive procedure’ for clicks on three test sessions. Comparing the thresholds obtained across two age groups, they found the older adults to perform poorer than the younger adults. In addition to temporal order threshold, its association with phoneme discrimination was also evaluated. A significant correlation was reported between phoneme discrimination and averaged temporal order thresholds obtained for tonal stimuli. The reason reported for the poorer performance by older adult group was the possible slower processing speed of the brain. From the finding of the study, Fink et al. recommended that temporal order measurement be done using tonal stimuli as it was found to have a high re-test reliability and positive correlation between temporal order measurement and phoneme discrimination abilities.

In contrast to the earlier studies, Fitzgibbons et al. (2006) used uniform and non-uniform sequences to evaluate the effect of age and hearing loss on temporal order recognition performance. The uniform sequences consisted of stimuli with equal inter-onset intervals (500, 350, 250, or 150 ms) while in the non-uniform sequences the inter-onset interval varied. The four groups considered in the study included young normal hearing adults aged between 19 to 40 years (mean age of 24.2 years), young adults with hearing loss aged 19 to 42 years (mean age of 28.2 years), old normal hearing adults aged 65 to 76 years (mean age of 71.8 years), & old adults with hearing loss aged 65 to 79 years (mean age of 73.1 years). They reported a significant effect of inter-onset interval and age on mean recognition scores for both uniform and non-uniform stimuli sequences. Hearing loss was noted to have a non-significant effect. They also observed better performance by the younger listeners compared to the older adult group at all the inter-onset interval considered.

In addition to studying the effect of age and gender on monaural perception of temporal order, Szymaszek et al. (2006) studied binaural perception. They compared the performance of young adults aged between 20 to 28 years (mean age of 24 years) with that of older adults aged between 60 to 69 years (mean age of 64.5 years). They found a significant effect of age, gender, presentation mode, and session. A significant interaction between presentation mode and age group was also reported by these authors. It was noted that the young adults had lower temporal order thresholds compared to the older adults group. Males, irrespective of the group, had better temporal order thresholds compared to females. The monaural presentation was reported to be more difficult compared to binaural mode of presentation. The differences observed in the two modes were noted to be due to the differential effect of age on the stimuli used in the two modes. A significant effect of age was only observed for tones presented binaurally and absent for the monaural clicks. The slowing of the temporal information processing with ageing was considered the cause for the poorer performance in the older adults.

Kumar and Sangamanatha (2011) evaluated binaural temporal sequencing abilities of 176 participants across six age groups in addition to binaural temporal resolution, duration discrimination and modulation detection. From the findings of the temporal sequencing test they observed that a significant difference in scores was found only for those age groups above 60 years (61 to 70 & 71 to 85 years). From the results, the authors concluded that temporal sequencing abilities to be more resistant to effects of ageing since the scores deteriorated only by the sixth decade of life. To explain the physiological mechanisms responsible for the age-related effects on temporal processing, the researchers extrapolated information from the near field studies on mice by Walton, Frisina, and O’Neill (1998). Kumar and Sangamanatha opined that older adults may have similar changes in responses of the inferior colliculus as observed in older mice by Walton et al. The changes noted in the mice included decrease in the number of neurons responsible for responding to short gap, lower magnitude responses to a stimulus after a silent gap and slower recovery patterns as well as altered neuronal map representing best frequency versus response latency.

Gordon-Salant and Fitzgibbons (1999) evaluated speech perception using a combination of temporal degradation tests (time-compression & reverberation) presented in quiet as well as in noise and psychoacoustic measures including temporal order discrimination. Forty participants were categorised into 4 groups: ‘young normal’ and ‘young hearing loss’ aged between 18 to 40 years, as well as ‘older normal’ and ‘older hearing loss’ aged between 65 to 76 years. They found a significant effect of age in all the psychoacoustical measures, but no significant effect was obtained for hearing status. They reported that for the older listeners to perceive a difference in temporal order, the duration of the stimuli had to be three times longer than that required by younger listeners. This was ascribed to the central origin of the temporal processing dysfunction. They found that the performances of the young and older adult groups could be differentiated from their performance on differential limens for complex gap detection and temporal order. Based on the results they concluded that, to accurately differentiate between individuals based on age and hearing status a combination of both speech and non-speech stimuli were required.

The findings of these studies on temporal ordering abilities in older adults indicate that the ability to correctly identify the sequence of stimuli deteriorated with age. This deterioration was observed for a variety of stimuli used and for both monaural and binaural stimulation.

2.1.1.3 Effect of age on temporal masking.

Temporal masking, the ability of one sound to mask another sound that precedes and / or follows it (Elliott, 1962), is a problem that has been found to be affected in older adults (Gehr & Sommers, 1999; Gifford, Bacon, & Williams, 2007; Newman & Spitzerb, 1983; Walton, Orlando, & Burkard, 1999). Researchers have evaluated temporal masking in older adults using forward masking, backward masking, as well as simultaneous forward and backward masking techniques.

The effect of auditory backward recognition masking was studied by Newman and Spitzerb (1983) in 10 elderly subjects (75 to 85 years, mean age of 80 years) with normal pure-tone thresholds between 500 and 6000 Hz. The performance of these individuals was compared with that of younger controls (20 to 29 years, mean age of 24.1 years) having normal hearing. Twelve silent inter-tone intervals (0, 20, 40, 80,120, 200, 240, 280, 320, 360, 400, & 440 ms) were used to separate the target stimuli and the masking stimuli. The authors reported that as the inter-tone intervals were gradually increased, the performance of both the groups improved and a plateau was reached between 360 to 440 ms by the elderly and 240 to 440 ms by the younger listeners. They also reported that the elderly performed poorer than the younger control group. Newman and Spitzer attributed the longer inter-tone intervals required by the elderly listeners to reach asymptotic performance level to the slower rate of processing of pure-tone stimuli compared to the younger controls. They also suggested that the faster rate of processing required for speech was much more than the channel capacity of the older adults resulting in an overload of the speech analysing mechanisms.

Similarly, Gehr and Sommers (1999) studied the effect of age on backward masking. They compared the performance of 5 older adults aged 67 to 82 years with that of 10 younger adults aged 18 to 24 years. The threshold for a 10 ms, 500 Hz sinusoid was measured in the presence of a 50 ms broadband masker presented with a delay of 1, 2, 4, 6, 8, 10, and 20 ms. Significantly higher thresholds were reported for the older adult group compared to the younger adult group at all the signal-masker delays. A significant effect of delay condition was reported with thresholds increasing with decreasing time delay between the signal and the maskers. The thresholds of the older adults were about 22 to 25 dB higher in the masked condition compared to the unmasked thresholds. Additionally, a steeper function between signal threshold and signal-masker delay was reported for the younger adults compared to the older adults. This was considered an indication of slower recovery from backward masking in these older adults. They suggested that the age related differences could be due to the influence of peripheral and central factors.

Recovery from forward masking was studied by Gifford et al. (2007) in older adults with normal hearing aged 60 to 75 years (mean age of 63.8 years) and were compared with young adults aged 19 to 30 years (mean age of 25.6 years). They obtained thresholds for a 20 ms 2400 Hz signal in presence of a 1675 Hz, 300 ms masker presented at 90 dB SPL. The signal-masker delays used was 2, 5, 10, 20, and 40 ms. The thresholds obtained for the older adults were significantly poorer compared that of the younger adults. This difference in the masked thresholds obtained were considered to be one of the reasons for the reduced ability of the participants to understand speech in amplitude modulated noise that was also studied by the authors.

In contrast to the earlier studies, Walton et al. (1999) studied the recovery of auditory brainstem responses from forward masking in a group of normal hearing young adults (mean age of 29.3 years, age range of 21 to 40 years) and older adults (mean age of 67.4 years, age range of 63 to 77 years). Auditory brainstem responses were obtained for 1, 4 and 8 kHz tone-burst with forward maskers of the same carrier frequency and 30 ms duration. The signal-masker delays utilised were 2, 4, 8, 16, 32, and 64 ms. They observed that wave V latency decreased and amplitude increased with increasing signal-masker delays for both groups. For the older adults, prolongation of wave V latency was observed even at the longest delay compared to younger adults as reported. This was observed although a significant difference in the wave V latency did not exist in the unmasked condition between the two groups. The greater shifts in wave V latency, observed in the older adults at 4 and 16 ms masker delays was considered as an indication of recovery from masking. However, a similar result was not reported for delays of 32 and 64 ms. They concluded from the result that with ageing, in tasks that require rapid encoding of signals, neural processing is affected.

The research on temporal masking indicates the amount of masking in older adults is much more compared to that in younger adults, irrespective whether it is a forward or backward masking task. The recovery from masking was also found to be much slower in this age group.

Overall, the research on the various temporal processing abilities brings to light the processing difficulties faced by older adults. These difficulties were observed for temporal resolution, temporal ordering, as well as temporal masking. Studies unanimously indicate the difficulties in these processes in older adults when compared to younger adults. The findings observed using behavioural methods have been confirmed using electrophysiological tests including ABR and MMN.

2.1.2 Effect of age on binaural integration.

The ability of individuals to process different auditory stimuli presented to each ear simultaneously, termed as binaural integration by ASHA (2005), is a difficulty noted in older adults by researchers (Gelfand et al., 1980; Jerger et al., 1995; Jerger et al., 1994; Roup et al., 2006). This ability has been found to be essential when multiple individuals talk simultaneously during group conversation (Bellis, 2003). Dichotic tests are popularly used to assess binaural integration.

In a retrospective study, Jerger et al. (1994) examined dichotic sentence identification of individuals having normal hearing or bilateral symmetrical hearing loss, age 9 to 91 years. With increase in age, an enhanced right ear advantage was observed, but the difference between the left and right ears increased due to a decrease in left ear scores. In both directed and free recall modes the performance was found to deteriorate with age in both ears. In addition, as age increased, females showed a higher performance deficit in their right ear and lesser deficits in their left ear, when compared to males. Jerger et al. proposed three possible hypotheses for the results observed in their study: Cognitive factors like memory that are known to decline with age; A larger effect of ageing on the auditory pathway transmitting the left ear input compared to the right ear input; and inefficient inter-hemispheric transfer of information in the corpus-callosum.

To determine the basis for the results obtained in their earlier study conducted in 1994, Jerger et al. (1995) evaluated both behavioural and electrophysiologic responses to dichotic stimuli. They observed a left ear disadvantage for a verbal task and a right ear disadvantage for a nonverbal task in an elderly group (73 to 84 years, with a mean age of 77.2 years). The electrophysiologic responses were found to complement the behavioural responses obtained. Jerger et al. suggested that the possible reason for the dichotic deficits observed in the older adults could be due to the progressive atrophy or progressive loss of myelination of corpus callosal fibres. This according to them resulted in a delay and reduced efficiency of inter-hemispheric transfer of auditory information.

Similar to the earlier studies, Roup et al. (2006) also reported better and homogenous performance on a dichotic word task in their younger group of normal hearing listeners (19 to 30 years, mean age of 25.6 years) compared to their elderly listeners (60 to 69 years & 70 to 79 years). It was observed that the elderly group, who had sensorineural hearing loss, had significantly better scores for both right and left ears in monaural presentation compared to dichotic presentation. Roup et al. (2006) also observed that the elderly group showed better performance in a directed attention condition compared to a free-recall condition. This was attributed to the effect of attention in the free recall condition, though the cognitive load was similar in the two conditions.

The studies by Jerger et al. (1994), Jerger et al. (1995), and Roup et al. (2006) used stimuli presented dichotically without any lag between them. Earlier, Gelfand et al. (1980) studied the effect of various temporal asynchronies (0 ms, 30 ms, 60 ms, & 90 ms) in groups of young listeners (17 to 28 years, mean age of 23.6 years) and elderly listeners (60 to 78 years, mean age of 66.6 years). It was reported that the younger group had significantly higher scores compared to the elderly listeners. The improvement in scores due to the asynchrony in presentation was observed for both the groups but was higher for the younger group. In addition, they observed significantly better right ear scores and average right ear advantages of similar magnitudes in both the groups. This was observed in spite of higher variability in the performances of the elderly group. A noticeable difference that the authors reported in the elderly listener was a different trend in the scores with the lag introduced into the stimuli. The younger group showed improved performance in their left ear in the 30 ms left lagging condition and improvement in right ear scores in right lagging condition. The elderly group showed improvement in the scores of both the ears when the lag was in either direction and left ear scores improved at a faster rate regardless of the lag direction. This was observed in the older adult group in whom the right ear advantage was maintained. This according to the authors occurred due to the effect of temporal masking on the stimuli when presented with a lag.

The review of the studies on binaural integration indicates that the ability to process signals presented to the two ears simultaneously or with a lag is affected in older individuals. This was observed despite studies differing in the test material that was used. While Jerger et al. (1994) used dichotic sentence test, monosyllabic words were used by Roup et al. (2006). Thus, irrespective of the type of material used, binaural integration has been found to be affected in older adults.

2.1.3 Effect of age on auditory separation / closure.

Difficulty in auditory separation / closure, assessed using stimuli with reduced external redundancy, is often reported to be a problem in older adults (Anderson et al., 2011; Cox et al., 2008; Dubno et al., 1984; Frisina & Frisina, 1997; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008; Wong et al., 2010). A common technique used to evaluate this difficulty is determining speech recognition in the presence of noise or in the presence of other competing stimuli (Bellis, 2003; Bellis, 2014). Other stimulus degradation methods used to evaluate auditory separation / closure are filtered, time or intensity altered speech.

Speech recognition in quiet and in the presence of noise were assessed by Dubno et al. (1984) who compared the performance of four groups of listeners. The groups consisted of younger (< 44 years, mean age of 27.9 years) and older (> 65 years, mean age of 70.5 years) normal hearing adults as well as younger (< 44 years, mean age of 34.1 years) and older adults (> 65 years, mean age of 73.4 years) with mild sensorineural hearing loss. In the quiet conditions they found a significant effect of hearing loss on speech recognition while age was found to have a non-significant effect for all the speech material evaluated (spondees, low & high predictability sentences). However, in the presence of noise, a significant effect of age and hearing loss was reported for speech recognition. Further, they reported that a significant difference existed between the signal-to-babble ratio of the < 44 and > 65 years groups that was observed irrespective of the hearing loss. They also found that articulation index values did not vary with age or hearing loss for speech in quiet. However, in the presence of noise it overestimated the performance of the older adults. Dubno et al. suggested that articulation index might not be able to accurately predict the performance in noise unless the age was taken into consideration for the calculations. Three possible reasons for the poor performance of the older adult group were suggested by the authors. These included auditory dysfunction associated with the cochlear mechanisms, deterioration in short-term memory, feature extractors and other mechanisms of the central auditory system as well as the changes in performance occurring with age due to a combination of peripheral and central auditory impairment.

A comparison of consonant recognition in quiet and in the presence of noise (cafeteria babble) in 64 listeners aged 21 and 68 years with normal hearing was carried out by Gelfand et al. (1986). The participants were divided into 5 age groups based on the decade they belonged to (20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, & 60 to 69 years). Performance was found to deteriorate with increase in age across the three signal conditions (quiet, MCL +10 dB, & MCL +5 dB). It was also observed that unvoiced final consonants recognition varied with the vowel. Significantly better consonant recognition in the context of /a/ rather than /i/ and /u/ was noticed. It was also reported that recognition of unvoiced final consonants was best with /u/ followed by /a/ and /i/. However, greater decline in consonant recognition was observed in the context of /i/ and /u/ with the addition of noise. The percentage of information transfer, both in quiet and in noise, was similar to that reported by Gelfand et al. (1985). Based on these findings, Gelfand et al. (1986) suggested that ageing affected perception of cues in the speech signal that were least robust in the young adult group, especially in the presence of noise.

Prosser et al. (1991) studied the relationship between decreased speech recognition of the elderly in presence of competing noise. Additionally, they studied the acoustic properties of the noise and the semantic content of sentences. It was found that the recognition scores were significantly affected by the type of noise and the signal-to-noise ratio. They studied four groups with 15 participants each [young normal hearing individuals (< 31 years), young individuals with hearing impairment (< 41 years), elderly normal hearing (65 to 81 years with hearing thresholds within 25 dB HL at 0.5-4 kHz), & elderly individuals with presbycusic hearing impairment (65 to 85 years)]. It was found that speech noise and cocktail party noise had major effects on speech discrimination abilities when compared to the traffic noise or continuous discourse. These effects were more noticeable at SNRs of 0 dB, -5 dB, and -10 dB than at +5 dB or +10 dB. The authors credited these to the stronger masking effect of speech and cocktail party noise that majorly had energy above 1 kHz and to the amplitude fluctuations in these types of noise. The lesser effect of traffic noise or continuous discourse was attributed to the reduced energy in the high frequencies and the amplitude fluctuations that were irregular and helped in the perception of the important cues for discrimination of speech. In addition, the slight decrease in the discrimination abilities observed in the elderly with normal hearing, though not significant, was ascribed to the effect of central and peripheral mechanism.

Age related difference in word identification in backgrounds of familiar and unfamiliar music and multi-talker babble was examined by Russo and Pichora-Fuller (2008). They studied a group of 8 younger adults (18 to 30 years, mean age of 21.1 years) and 8 older adults (65 to 78 years, mean age of 69.4 years). Using sentences from the ‘Revised Speech Perception in Noise’ tests, they reported that the speech identification for sentence final target words was better for high-context sentences than for low-context sentences and better at higher speech to babble condition (4 dB speech to babble condition than 0 dB). Better identification was reported when the background was music than when it was multi-talker babble. It was also found that the type of background (music from the 1950s, music from the 1990s and multi-talker babble) did not have any significant effect on the word recognition of the elderly group, but had significant effect on the younger group. This was more noticeable at lower speech-to-babble conditions. From the results, it was construed that better recognition in the background of music was due to the dissimilarity between speech and background music than background babble. Additionally, they opined that the regular dips in the amplitude of music waveforms helped in the perception of important features required for recognition of speech.

Speech perception in the presence of noise and the ability to recall sentence-final words presented in speech babble was assessed by Pichora-Fuller et al. (1995). This was studied a group of young adults with normal hearing aged 22 to 29 years (mean age of 23.9 years), older adults with near-normal hearing aged 65 to 77 years (mean age of 70.4 years), and an older adult group with presbycusic hearing loss aged 67 to 91 years (mean age of 75.8 years). Perception of speech in various signal-to-noise ratios was found to affect the older groups more than the younger group. The older adult group with near normal hearing were reported to perform better than the group with presbycusic hearing loss on both high and low-predictability sentences. The maximum difference between the two sets of sentences was lager for the older adult group compared to the younger group. This was considered to indicate that the older adult group depended more on the contextual cues that were available compared to the younger group, even in conditions that were regarded as favourable. Further, Pichora-Fuller et al. (1995) found that the older participants recalled lesser number of words than the younger participants in the presence of noise. This was also present for both high- and low predictability sentences. The possible reason for this difference, according to the authors, was the increased allocation of resources for the perception of speech in the presence of noise, which in turn reduced the resources available for storage and retrieval. This was considered to occur due to the age related deterioration in the auditory system. An alternative explanation provided was that due to the perceptual processing difficulties, the mental representation of the words in memory was degraded or less stable in older adults.

Findings similar to that of Pichora-Fuller et al. (1995) were obtained by Frisina and Frisina (1997) in a study on the perception of sentence-final words in the presence of multi-talker speech babble. Frisina and Frisina (1997) compared speech recognition abilities of five groups of listeners on the perception of speech in quiet and in background of speech babble. The groups included young normal hearing aged 19 to 39 years (mean age of 25.5 years), older adults aged 60 to 81 years with normal hearing (mean age of 65.5 years) and three other older adult groups with presbycusic hearing loss (mean ages of 70, 70.1 & 72.3 years). The older adult groups with hearing loss differed in the pure-tone thresholds at 4 kHz. They found a significant effect of group and test material used by them on speech recognition in quiet. On further comparison, they observed that the young normal hearing and the elderly normal hearing groups performed similar to each other. The performance of the older normal hearing group was better than that of the three groups with hearing loss. The performance on low- and high- predictability sentences, considered as a measure of cognitive function, were similar. However, in the presence of noise the performance of the young normal hearing group was better compared to the elderly group with normal hearing. Similar performance was reported for all the older adult groups expect for low-predictability sentences in which the elderly with normal hearing performed better. The difference between the performance on the low- and high- predictability sentences was similar to that observed in quiet.

The relationship between the neuroanatomical structures of the brain responsible for cognitive functioning and the perception of speech-in-noise was assessed by Wong et al. (2010). Using magnetic resonance image, seven regions were evaluated that included the regions of cognitive significance in the dorsal and ventral prefrontal cortex (caudal middle frontal gyrus, rostral middle frontal gyrus, superior frontal gyrus, pars opercularis, and pars triangularis), the precuneus and the auditory cortex (superior temporal region). A group of 15 older listeners, aged 62 to 75 years (mean age of 67.1 years), and a younger group of 14 participants, aged 18 to 27 years (mean age of 21.1 years) were studied. The two groups were compared on the relationship between the ability to perceive speech in noise using QuickSIN and magnetic resonance image. Wong et al. found that among the seven regions considered, caudal middle frontal gyrus, superior frontal gyrus, precuneus and superior temporal region were predictive of the ability to perceive speech in the presence of noise in the most unfavourable condition that was tested (0 dB SNR). They also reported that these areas were known to be associated with executive functioning, working memory, and attention. The authors interpreted their results using the decline-compensation hypothesis that suggested an increased involvement of the general cognitive areas to compensate for the reduced sensory processing in elderly listeners.

Anderson et al. (2011) assessed the relationship between subcortical representation of speech and speech perception ability in noise using auditory brainstem response for complex sounds. Twenty-eight elderly listeners aged between 60 to 73 years (mean age of 63.1 years) were studied. These listeners were grouped according to their Hearing-in-Noise-Test scores as top speech-in-noise and bottom speech-in-noise group. The /da/ stimulus used to measure auditory brainstem response for complex sounds was presented in a background of 6-talker babble at +10 dB SNR relative to the 70 dB SPL noise. The authors reported that better Hearing-in-Noise-Test scores were significantly associated with larger F0 and root-mean-square amplitudes in both conditions. A significantly higher correlation between the responses obtained in quiet and in noise was observed for the top speech-in-noise group compared to the bottom speech-in-noise group. The authors attributed the better subcortical encoding of F0 to the better perception in noise in the top speech-in-noise group. They also opined that F0 and other cues for pitch perception helped the participants identify the target voice and to separate it from the background of other competing voices. However, the older participants benefited less from the cues and this was considered to reflect their deficits in encoding pitch information. The authors also ascribed the reduced ability to process cues for pitch perception to decreased γ- aminobutyric acid (GABA) inhibition due to ageing. It was believed that for stronger F0 encoding in the top speech-in-noise group, GABA inhibition might be partly responsible.

Cox et al. (2008) evaluated elderly listeners (66 to 85 years) divided into three groups based on their hearing thresholds. Group 1 had normal hearing from 500 to 4000 Hz; Group 2 had high frequency sloping hearing loss; and Group 3 had both low and high frequency hearing loss. The participants were assessed on a battery of monotic tests to assess auditory processing abilities including auditory closure. The tests used by Cox et al. included low pass filtered test assessing auditory closure; pitch pattern sequence - adult test that assessed temporal sequencing, QuickSIN and Synthetic sentence identification in ipsilateral competing message that evaluated comprehension of speech in noise; time compressed sentence test and random gap detection test that tapped temporal integration. They reported that hearing thresholds had a significant effect on the performance on the time compressed sentences test (sentences and words) at 60% compression as well as on the filtered speech test. The performance of Group 3 was found to be poorer compared to Groups 1 and 2. The authors also reported that the effect of cognitive factors (working memory, speed of processing and executive control process) was negligible in the elderly listeners. Cox et al. concluded that hearing loss in the speech frequency range affected performance on tests of auditory processing abilities, but age had minimal effects. In addition, QuickSIN test was reported to be more resistant to peripheral hearing loss when compared to other auditory processing tests like Synthetic sentence identification in ipsilateral competing message, low pass filtered speech test and time compressed speech test.

The above research on auditory separation / closure abilities of older adults highlights their reduced ability to separate speech from background noise. This was observed irrespective of the noise type used. The findings from the behavioural studies have been supported by the findings of the electrophysiological / neuroimaging studies in these individuals.

2.1.4 Effect of age on binaural interaction.

The ability of the two ears to work together while processing the same / parts of the same stimulus, termed as binaural interaction, according to Bellis (2003) is considered important in localization and lateralization of auditory stimuli, detection of signal in presence of noise, binaural release from masking, and binaural fusion. The most commonly used test to assess binaural interaction is a Masking Level Difference task with either tonal or speech stimuli. Difficulties in binaural interaction with age have been noted by researchers (Grose et al., 1994; Pichora-Fuller & Schneider, 1991; Strouse et al., 1998).

Impaired binaural processing, as assessed using ‘Masking Level Different’ was considered one of the factors that contributes to the difficulties in understanding speech in presence of background noise by Grose et al. (1994). They examined Masking Level Difference in older listeners (63 to 80 years, mean age of 72.8 years) who had pure-tone thresholds equal to or less than 20 dB in the frequencies 250 to 2000 Hz. They also evaluated a younger control group (21 to 25 years, mean age of 22.6 years) who had normal hearing. Two different paradigms of Masking Level Difference, one using tones and the other using spondaic words were assessed. It was found that for both pure-tone and spondaic words, the elderly listeners performed poorer than the younger listeners. This difference between the two groups was significantly more in the N_0S_π condition. The authors construed from their results that the poor binaural processing ability in the elderly group with near normal hearing could contribute to their difficulties in perception of speech in the presence of noise. This was considered to occur since binaural cues were important for localization of the source and separation of the target speech from background noise.

Pichora-Fuller and Schneider (1991) studied the effects of age on the MLD in 12 young adults in the age range of 20 to 25 years (mean age of 22.3 years) and 12 older adults between the ages of 63 to 73 years (mean age of 68.5 years). All the participants had normal hearing thresholds (≤ 25 dB HL). Five different experiments were conducted. In the first experiment, threshold for detection of a 500 Hz pure-tone in the presence of burst and continuous noise was evaluated in a diotic condition (S_0N_0). They reported that no significant difference was found for the detection threshold for the two groups of listeners, which according to the authors suggested that both groups were equally sensitive to the pure-tones masked by the noise.

In the second experiment, four dichotic conditions were used ($S_\pi N_0$, $S_0 N_\pi$, $S_0 N_\tau$, &, $S_\pi N_{\pi\tau}$). The dichotic thresholds were obtained in the presence of burst noise. The older group were found to have significantly poorer dichotic thresholds and MLDs compared to the younger group. They also reported that a significant difference was found for thresholds obtained by the younger group in $S_\pi N_0$ and $S_\pi N_{\pi\tau}$ conditions. In the third experiment, dichotic thresholds in the four dichotic conditions used in experiment two were obtained in the presence of continuous broadband masking noise. The results obtained were similar to those obtained in experiment two.

In the fourth experiment, Pichora-Fuller and Schneider (1991) studied the threshold for the homophasic condition ($S_\pi N_\pi$) in the presence of burst and continuous background noises. The results indicated that age had a significant effect on the homophasic thresholds only in burst noise background. They reported that these results were suggestive of the inability of the older subjects to process homophasic stimuli.

In the fifth experiment, the effect of frequency of the MLD thresholds was evaluated. Thresholds were obtained under homophasic ($S_\pi N_\pi$) and dichotic conditions ($S_\pi N_{\pi\tau}$) for three frequencies (250, 667 and 909 Hz) in presence of background noise. It was reported that the younger group obtained better thresholds than the older group. The MLDs obtained by the older group were also reported to be smaller at all three frequencies. Pichora-Fuller and Schneider reported that the age related differences obtained at 500 Hz were also observed at other frequencies. From the results of the five experiments, it was concluded that it was possible to identify the effect of ageing on monaural and binaural processing, which would affect the detection of signals in everyday life.

Strouse et al. (1998) measured MLD along with temporal processing using speech stimuli in younger and older normal hearing individuals. They used continuous speech noise presented in phase (N_0) and measured speech reception threshold with speech presented either in phase (S_0) or 180^0 out of phase (S_π) binaurally. They reported a significant difference between the MLD obtained for the two groups, with the older listeners performing poorer than the younger group. These results were similar to that obtained by Pichora- Fuller (1991) and Grose et al. (1994) who used pure-tone stimuli and speech stimuli respectively. Strouse et al. concluded from the results of their study and from results of previous studies (Grose et al., 1994; Pichora-Fuller & Schneider, 1991) that a significant decline in the binaural release from masking was seen as age progressed.

The findings of the above studies reveal the presence of difficulties in binaural interaction in older adults, irrespective of the stimuli used. This difficulty in binaural interaction has been reported to be one of the reasons for difficulties experienced by older individuals in perception of signals in the presence of noise.

2.2 Effect of ageing on electrophysiological test findings

Electrophysiological tests have been noted to be useful in determining the effect of ageing on processing of auditory signals (Tremblay, Billings, & Rohila, 2004). These studies have used cortical potentials (Tremblay et al. 2004; Stenklev & Laukli, 2004; Bellis, Nicol, & Kraus, 2000) and subcortical potentials (Werff & Burns, 2011). Both speech and non-speech signals have been utilised to evaluate auditory perceptual deficits in older individuals (Bellis, Nicol, & Kraus, 2000; Leigh-Paffenroth & Fowler, 2006; Tremblay, Billings, & Rohila, 2004).

Tremblay et al. (2004) examined the effect of complexity of stimuli and the rate of stimulus presentation in two groups of participants, one younger (aged 21 to 33 years) and the other older (aged 63 to 79 years). Ten participants from each group were evaluated to obtain N1-P2 complex using tone-bursts and the speech stimulus /pa/. Both stimuli, equal in duration and intensity, were presented using three inter-stimulus intervals. The three inter-stimulus intervals represented a medium rate of presentation (910 ms), a fast rate of presentation (510 ms), and a slow rate of presentation (1510 ms). Significantly prolonged latencies of N1 and P2 were found for speech stimuli in the older listener compared to the younger listeners. These were evident at Cz site and also surrounding recording sites. However, a similar difference was not found for the tonal stimuli. They also found that for the speech stimuli, P1 latency did not vary for the two groups across the three inter-stimulus intervals. In contrast, they reported that N1 latencies were significantly prolonged in the older adults compared to the younger listeners for the medium and high stimulus presentation rates. The P2 response was reported to be prolonged for the elderly listeners for all the three stimulus presentation rates.

For the tonal stimuli of their study, Tremblay et al. (2004) reported that P1 and P2 responses did not show any significant difference with reference to age or stimulus presentation rates. On the other hand, the latencies of N1 responses were reported to be delayed only for higher presentation rates. For the amplitude measures Tremblay et al., noticed that for the speech stimuli, P1 amplitude did not vary with either age or stimulus presentation rates. The N1 and P2 amplitudes showed a decrement with increase in stimulus presentation rates irrespective of the age. Unlike the younger group, the older group obtained larger P1 amplitude, smaller N1 amplitude, and reduced amplitude with increase in stimulus presentation rates. The P2 amplitude was also found to reduce with increase in stimulus presentation rates, but was independent of the changes in age. The age related changes in latency and amplitude of the cortical responses were attributed to the changes in the refractory periods of the neurons. According to the authors, the auditory system of the elderly listeners requires longer time to recover from the initial excitation to be able to fire for the next stimuli. These were reported to affect the synchrony of neural activity. These variations in the synchronous neural activity were considered to explain a part of the difficulties experienced by older listeners in understanding speech.

Hemispheric asymmetry in processing speech sounds was studied by Bellis et al. (2000) using auditory cortical P1-N1 responses and mismatch negativity (MMN) in 3 groups of right handed subjects with normal hearing. The participants included 15 children aged 8 to 11 years, 11 young adults aged 20 to 25 years, and 10 older adults above the age of 55 years. The auditory cortical P1-N1 responses as well as mismatch negativity (MMN) were measured using synthetic speech syllables /da/ and /ga/. Fine grained discriminations of two continua /da/ to /ga/ and /ba/ to /wa/ were obtained. The continuum /da/ to /ga/ differed in the third formant onset frequency and the continuum

/ba/ to /wa/ differed in the duration of first and second formants. A greater degree of temporal lobe asymmetry was reported for children and young adults when compared to older adults. It was observed that the responses from the left hemisphere were significantly larger than the responses from the right hemisphere in children and younger adults. However, these differences were not significant in the older adults. In addition, it was reported that the P1-N1 peak-to-peak amplitude were significantly larger over the left temporal lobe than on the right temporal lobe for children and younger adults, whereas a symmetrical response was reported for older adults. The MMN responses for the left and right hemisphere were not significantly different for the three groups. The fine grain discrimination of /da-ga/ stimulus contrasts were reported to be poorer for the older adult group compared to the younger adults and children. From the results, it was construed that ageing had an effect on the neural representation of speech sounds in normal hearing individuals. It was also suggested that the age-related alterations in the hemispheric asymmetry in neural representation of elemental speech could be one of the factors that may contribute to temporal processing difficulties exhibited by ageing adults. A possible change in the generator site for the P1-N1 response was also suggested to result in their observations.

Amplitude modulated ASSRs was used as a physiologic measure to assess phase locking capability for temporal processing in a group of younger (≤ 41 years) and older adults (≥ 63 years) by Leigh-Paffenroth and Fowler (2006). Sinusoidally amplitude modulated pure-tones with modulation rates of 20, 40, and 90 Hz were used with carrier frequencies of 500 and 2000 Hz. It was observed that the younger and the older listeners differed in the degrees of phase locking capabilities for both carrier frequencies and rate of modulations. The younger listeners consistently showed more phase locked responses compared to the older listeners for 500 Hz carrier frequency. It was observed that for 2000 Hz carrier frequency, at modulation rates of 20 and 90 Hz, older listeners showed similar number of responses as younger listeners but at 40 Hz showed more number of responses compared to the younger listeners. The correlation between the number of phase locked responses and speech recognition abilities for low predictability sentences revealed a significant correlation at 500 Hz, but was absent at 2000 Hz. The correlation showed that as the word recognition scores reduced, the number of phase locked responses also reduced. The hearing threshold and the number of phase locked responses at 500 Hz and 2000 Hz revealed a significant correlation only at 500 Hz. As the hearing thresholds improved, the number of phase locked responses also increased. The results obtained were ascribed to the effect of ageing on neural synchrony. In addition, it was suggested that the temporal coding of low frequency signals were affected by ageing but the temporal coding of high frequency signals were not affected.

The electrophysiological studies assessing the cortical processing in older adults indicate the presence of deficits in auditory processing. This has been observed for speech and non-speech stimuli. Older adults were found to demonstrate increased latencies and reduced amplitude of cortical responses measured using LLR and MMN.

2.3 Rehabilitation options available for auditory processing

A number of management options / programmes have been developed for the use of individuals with auditory processing disorders (APD). However, as evident from the literature and according to Baran (2002) these approaches have mainly focused on children and rehabilitation for adults have not been given much importance. According to Baran, the reason more emphasis has been given to the children is due to the increasing number of them who are diagnosed as having APD. Hence, the review of literature provided below on management options for APD are mainly those meant for children but can be adapted for adults. These management options for individuals with APD have been classified in different ways in literature. A few of these classifications have been provided by Young and Protti-Patterson (1984), Chermak and Musiek (1992, 1997, 2002) and Bellis (2003).

Young and Protti-Patterson (1984) classified management procedures for children with APD as top-down and bottom-up approaches. Additionally, they also described an integrated approach that included both top-down and bottom-up approaches. A top-down approach has been described by them as those procedures that assess and remediate the components of language that include phonology, morphology, syntax, semantics, and pragmatics. The bottom-up approach has been described as including strategies to improve the accuracy of acoustic signal reception and transmission. These included auditory training along with the use of preferential seating, use of visual cues, reduction of auditory and visual distractions, and reduction of background noise.

Chermak and Musiek (1992, 1997, 2002) described the management of CAPD under two broad headings. The first included complementary interventions that incorporated auditory training as well as metalinguistic and metacognitive approaches. The second approach included strategies to enhance the quality of the acoustic signal and the listening environment. Likewise, Bellis (2003) classified management options into three main categories: environmental modification and teaching suggestion to improve auditory information; enhancement of discrimination, inter-hemispheric transfer of information and other neuro-auditory functions; and compensatory strategies.

Thus, it can be seen that though different terminology have been used to classify remediation techniques for individuals with APD, they directly or indirectly address the similar issues. Taking into consideration the major classifications that are available in literature, the management for APD that may be more appropriate for older individuals may categorised as follows: Enhancement of the quality of the acoustic signal and the listening environment; Compensatory strategies that include metalinguistic and metacognitive approaches and direct remedial techniques that use auditory training.

2.3.1 Enhancement of the quality of the acoustic signal and the listening environment.

It has been well established that individuals with APD have considerable difficulty perceiving speech in poor acoustic situations. In order to enhance their perception of acoustical signals, environmental modifications have been suggested (Bellis, 2002; Bellis, 2003; Chermak & Musiek, 1992; Keith & Fallis, 1998). Additionally, to improve the quality of acoustic signals, Bellis (2002) recommended the use of assistive listening devices (personal or sound field), besides architectural changes for reduction of reverberation and to improve signal-noise-ratio, removal of sources of noise inside and outside the room. Similarly, Chermak and Musiek (1997) advocated the use of personal or sound field FM technology, alterations of the classroom acoustics, reduction of background noise and reverberation and maintenance of an optimal distance between the listener and the sound source.

From literature, it is evident that the use of environmental modifications has been recommended for close to three decades to enhance listening in individuals with APD. Although environment modifications have been recommended for a fairly long duration, not much importance has been given to confirming their utility in individuals with APD. However, studies done on the general population have revealed that the reduction of noise levels and reverberation do bring about improved speech perception (Crandell & Smaldino, 2000; Klatte, Lachmann, & Meis, 2010; Mershon & King, 1975). The focus on environmental modifications in the habilitation of individuals with APD has depleted after direct remedial techniques gained popularity.

2.3.2 Compensatory strategies.

Compensatory strategies have been described as a top-down approach by Young and Protti-Patterson (1984). According to ASHA (2006) and Young and Protti-Patterson these strategies do not resolve the central auditory processing deficiencies, rather these are reported to circumvent these deficiencies. These strategies were considered to strengthen the higher order central resources (language, memory, & attention). The strengthening of these resources helped individual with auditory processing deficits to overcome the deficiencies and enhance listening, communication, social and learning outcomes. The metalinguistic approach included aspects that facilitated the efficient reception and processing of the auditory information such as discourse cohesion devices, schema induction, context derived vocabulary building, segmentation, prosody and metamemory. The metacognitive approach on the other hand included the appropriate application of knowledge to plan, monitor, and regulate the performance. The many metacognitive approaches included attribution training, cognitive behaviour modification, cognitive processing style, reciprocal teaching, and assertiveness training. Despite metalinguistic and metacognitive approaches being recommended for clinical use, their utility have yet to be proven scientifically.

2.3.3 Direct Remedial Training in children.

A review of literature on direct remedial techniques reveal that though the techniques were advocated in the 1990's, research to prove that the procedures do help were mainly carried out in the last decade. Several techniques have been suggested, but have not been verified empirically. Additionally, the focus of most of the studies on direct remedial techniques has been on children. Not much has been done to check if direct remedial training helps improve auditory perception in adults. However, the techniques that have been reported in literature to be used with children can be adapted to be used with adults. Studies on direct remedial techniques reported in literature have utilised auditory training activities to enhance different auditory processes.

Chermak and Musiek (1992, 1997) categorized auditory training as formal and informal training. They reported that formal auditory training tasks utilize a rigorous acoustically trained paradigm involving nonverbal and simple speech elements. This technique was considered to specifically improve basic auditory skills that included temporal gap detection, intensity discrimination, frequency discrimination and speech recognition skills. The informal auditory training method was reported to utilise verbal stimuli and focus on the use of linguistic context or language based tasks to help in auditory function. Components of informal training were also included in metalinguistic and metacognitive approaches advocated by Chermak and Musiek (1997). Although

Chermak and Musiek (1997) recommended the use of auditory training, they did not provide any evidence that the procedures could be useful for individuals with APD.

Studies demonstrating the benefit of auditory training targeting specific auditory processes are relatively few. These studies have utilized activities to enhance binaural integration (English et al., 2003; Katz et al., 1984; Priya & Yathiraj, 2007; Yathiraj & Mascarenhas, 2003), auditory separation / closure (Maggu & Yathiraj, 2011a; Yathiraj & Mascarenhas, 2003), and temporal processing (Maggu & Yathiraj, 2011b; Yathiraj & Mascarenhas, 2003).

Auditory integration: In a study to tap auditory integration, Katz et al. (1984) evaluated the effectiveness of dichotic-offset training in 10 children with auditory processing disorder who were aged 7 to 10 years. The children who experienced difficulty on the staggered spondaic word test were provided with systematic dichotic listening sessions. The dichotic-offset training was given for two one-hour sessions per week. They reported improved performance on the staggered spondaic word test and Speech-in-noise, though it was not statistically significant.

In another study to improve auditory integration, English et al. (2003) evaluated the effects of training on the scores of dichotic digit test in a group of 10 children (mean age of 8.2 years) with reduced scores in the left ear. The authors stimulated only the left ear of the participants using recorded speech material for 10 to 13 weeks (mean = 11.2 weeks). They reported an improvement in the mean left ear scores on the dichotic digit test following auditory stimulation. The scores of nine out of the 10 children were reported to be age appropriate after stimulation. According to English et al., stimulation of the left ear resulted in improvement in the ability of the right hemisphere to process auditory input and resulted in improvement in dichotic digit test scores.

The impact of training to improve auditory integration was described by Priya and Yathiraj (2007) using dichotic offset training material developed by Yathiraj (2006). This material was similar to that used in the programme developed by Katz et al. (1984). Twelve children (7 to 12 years) who failed a screening checklist for auditory processing, dichotic CV and a dichotic digit test were provided the training. The dichotic-offset material consisted of 12 dichotic words-lists out of which six lists consisted of monosyllables with blends and the other six, monosyllables without blends. The offset lag used were 500 ms, 300 ms, 200 ms, 100 ms, 50 ms and 0 ms. The children were trained for 10 to 15 sessions with the offset lag gradually being reduced. It was observed that the children obtained significantly better single and double correct scores in the dichotic CV test following training. Significant improved performance in only the right ear single correct score was reported on the dichotic digit test. Based on the results they concluded that dichotic offset training was effective in helping children with deficits in binaural integration.

Auditory separation: In an attempt to improve auditory separation, Maggu and Yathiraj (2011a) conducted a study to evaluate the effectiveness of noise desensitization training in 10 children. The children aged 8 to 11 years, with poor speech-in-noise scores were recruited for the study. Half the children received training and served as the experimental group and the remaining served as the control group. Training was provided using three types of noises (environmental noise, speech noise and multi speaker babble), presented in a hierarchy of six levels and signal-to-noise ratios. The five children who received noise desensitization training were reported to obtain significantly higher scores on three different tests (monosyllable speech identification test, speech discrimination test, & High frequency English speech identification test) in the presence of noise unlike the control group. The authors suggested that the training could have resulted in neurophysiological changes in the experimental group. They speculated that similar to what happens during tinnitus retraining therapy, the training could have prevented the noise from reaching the autonomic nervous system and interfering with the signal. They also attributed the improvement in speech perception in noise to neuroplastic changes in the central auditory.

Temporal processing: Maggu and Yathiraj (2011b) studied the effectiveness of temporal pattern training on temporal processing in children with APD. Additionally, they also evaluated the effect of the training on other auditory processes. The children aged between 8 to 13 years were randomly assigned to an experimental and control group, with each group having five participants. The experimental group was trained on temporal patterning and the control group did not receive any training. The training was provided used tones having three different frequencies (500, 1000 and 4000 Hz) with durations that varied from 250 ms to 500 ms. The stimuli were presented in clusters of 2-tones, 3-tones or 4-tones in a hierarchical manner. It was reported that after training, significant improvement was observed on duration pattern test. From the results, the authors concluded that direct remediation did have a positive effect on temporal processing. It was also observed that improvement was found for other auditory processes like auditory memory and sequencing. It was inferred from the results that the use of nonverbal stimuli in training helps in improvement in central auditory processing.

Multiple process training: Yathiraj and Mascarenhas (2003) evaluated the effectiveness of auditory stimulation in children with auditory processing disorder. Ten children, aged 7 to 12 years, were randomly divided into an experimental group and a control group, with 5 children each. The children in the experimental group were trained on several processes including phoneme synthesis, auditory integration, auditory separation, recognition of low redundancy sentences, auditory memory (recall & sequencing), and duration pattern recognition. Before the training was initiated, all the children were assessed on tests tapping different auditory processes (dichotic CV test, SPIN, duration pattern test, & auditory sequencing). After 30 sessions of training, it was reported that a significant improvement was seen in the double correct scores of dichotic CV test, auditory sequence test, duration pattern test, and SPIN. They also reported that the improvement was generalised to other skills also. It was concluded from the results that the deficit specific intervention not only led to improvement in the targeted auditory process but also led to improved performance in a real life situation.

The effect of informal and formal auditory training on temporal processing abilities in 15 children (age between 7 to 10 years 11 months) was assessed by Vilela et al. (2012). The participants were divided into three groups, a control group who did not receive any training, the second group who received informal training and the third group who received formal training. The informal auditory training included training for temporal ordering, inter-hemispheric transfer, closure, verbal memory, verbal figure ground, nonverbal figure ground, and nonverbal closure. These were carried out using increasing number of stimuli and in the presence of noise at various signal-to-noise ratios. The formal training included intensity discrimination training, frequency discrimination training, temporal training, dichotic speech perception training, and training for speech perception in presence of noise. It was reported that the two groups of children who were trained with the formal and the informal auditory training showed significant improvement on pitch pattern sequencing and duration pattern sequencing tests. Further, it was reported that the difference between the amounts of improvement between the two groups was not significant. However, the variability in the scores observed in the study was very high in each of the three groups.

The literature on direct remedial techniques on children having auditory processing problems has demonstrated positive results. The positive impact has been shown for a variety of processes using varied techniques. While several studies have tapped specific auditory processes, others have provided training on multiple processes, depending on the need of the individual.

2.3.4 Direct Remedial Training in adults.

Studies carried out to evaluate improvement in auditory processing in children are relatively few. However, studies to assess improvement in adults are more limited. One such study was carried out by Musiek, Baran, and Shinn (2004). They trained a single case (41 year old female) with head injury to produce of clear speech, reauditorization, dichotic interaural difference, auditory memory enhancement, auditory speech discrimination, temporal sequencing, and the use of metacognitive strategies. Before the therapy was initiated, the performance on a competing sentence test, dichotic digits and compressed speech test were assessed and found to be below normal levels and the left ear was reported to have greater deficits. They reported that after training, improvement was observed both for auditory and cognitive functioning. In the auditory domain, the dichotic test scores were reported to be within normal limits and the scores of compressed speech and competing sentences were found to be at near normal levels of performance in both ears. They also observed improvement in the amplitude and waveform morphology measures of middle latency responses. On the cognitive domain, improvement was reported in the ability to recall and share information about conversation, short term and long-term memory, organization skills, concentration and the speed of thinking. According to them, the comprehensive training plan helped in improvement of auditory and cognitive skills. However, the possibility of spontaneous recovery after the head injury may have contaminated the results. Hence, there is a high possibility that the results observed in the study may not be wholly due to the training that was provided.

A few studies have evaluated the efficacy of various training methods in older adults with and without hearing loss. These studies have focussed on cognitive functioning, speech in noise processing, and auditory cognitive functioning (Anderson, White-Schwoch, Choi, & Kraus, 2013; Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013; Mahncke et al., 2006).

Mahncke et al. (2006) evaluated the effectiveness of a brain-plasticity based training programme in older adults above the age of 60 years (age range of 60 to 87 years). The training programme focussed mainly on age-related cognitive decline. Among the various tasks considered, they reported significant improvements in speed of processing, and forward recognition memory span after 30 sessions of training. They reported that the improvements following training were generalised to other measures of memory performance assessed using Repeatable Battery for the Assessment of Neuropsychological Status. Maintenance of these improvements following training was also reported to be maintained 3-months after the training was discontinued. The improvement in the flow of information through the auditory and language systems in brain was considered to have led to the enhanced performance.

In line with the research by Mahncke et al. (2006), a study conducted by Anderson, White-Schwoch, Choi, et al. (2013) assessed the efficacy of an auditory-cognitive training programme in older adults with and without hearing loss. Out of the 58 older adults between the ages of 55 to 79 years, 29 were assigned to a training group and the other 29 to an active control group. The auditory-cognitive training programme ‘Brain Fitness’, consisting of six different modules to improve speed and accuracy of auditory processing was used. The six modules of the training programme included time order judgement of frequency-modulated sweeps, discriminating between similar syllables, repeating sequences of syllables and words, matched pairs of syllables and words, remembering multipart commands, and remembering details of stories. The participants were evaluated on speech perception in noise and two subtests of the Woodcock-Johnson III Cognitive Test Battery (short-term memory & attention). They reported that training had differential effects on the performance of the two groups. The group with normal hearing improved on memory while the group with hearing impairment showed improved speech-in-noise performance. Both the groups were reported to show significant improvement in attention. The behavioural changes observed were reported to be due to a reduction in the neural representation of the speech envelope in presence of noise, which was similar to those observed in normal hearing older adults. No changes in performance were reported for the active control group participants.

Using the same training programme (Brain Fitness), Anderson, White-Schwoch, Parbery-Clark, et al. (2013) demonstrated improvements in the neural response timing in 35 older adults compared to 32 older adults who served as active controls. The auditory brainstem responses to speech stimuli showed decrease in the latencies for formant transition cues, both in quiet and in noise. They also reported reduced inter-peak variability in noise, and reduced shifts in neural response timing in the presence of noise. These changes were reported to be associated with changes in behavioural measures of speech-in-noise, auditory short-term memory and processing speed. The authors reported that increase in inhibitory neurotransmitters like gamma-aminobutyric acid and other excitatory neurotransmitters that contribute to sharper neural tuning as mechanisms responsible for changes due to training.

In a recent study, Morais et al. (2015) trained 16 older adults with auditory processing deficits. Their participants, aged between 60 and 78 years, had hearing thresholds less than 40 dB HL and deficits in two of the four auditory processes they assessed. The processes and the tests used to asses these processes included auditory closure (Speech-in-Noise), dichotic listening (Dichotic Digit Test), temporal ordering (Pitch Patten sequence), and temporal resolution (Gap-In-Noise test). Additionally, P300 was recorded for tone bursts (800 Hz frequent & 1200 Hz infrequent) and synthesised speech syllables (/da/ frequent & /wa/ infrequent). Two evaluations were performed before the initiation of training. The older adults were trained using ‘acoustically controlled auditory training’. Under the training programme in every session each participant was trained on the auditory processing skill they failed. At the end of each session, information was provided on the use of communication strategies and homebased activities to be carried out. After 8 weeks of training, with one training session per week lasting 50 minutes, they observed that the behavioural tests showed improvements following the training while changes were not observed in the cortical potentials for speech and tone burst stimuli. They suggested that the improvement seen following the intervention was due to the training-induced neural plasticity in these older adults.

The review on the auditory processing problems in the older population reveals that considerable emphasis has been given to identify their perceptual problems. The results of these studies indicate the presence of auditory processing deficits in the absence of any peripheral hearing deficits in these older individuals. Similar results have been reported by researchers assessing auditory processing skills using various stimulus types and conditions. The studies also indicated a close relationship between temporal resolution abilities and speech perception abilities in the presence of noise. Although extensive research is available on the auditory processing deficits, relatively less research has been carried out on remedial procedures that can be utilised by older adults. The majority of the studies on rehabilitation of individuals with APD have been done on children. The few studies that have been carried out on adults have provided training using a variety of procedures. This makes it difficult to pinpoint the exact technique that was helpful.

Chapter 3

METHODS

The current study aimed to determine the efficacy of temporal resolution training in older adults with near normal hearing and establish its effect on a series of tests (Gap-In-Noise, gap detection, duration pattern, dichotic CV, speech-perception-in-noise, voicing discrimination, & auditory memory and sequencing). In the study, a time-series design with purposive sampling technique was used. The study was carried out in the following five phases:

Phase I: Development of material

Phase II: Selection of participants

Phase III: Pre-training baseline evaluations (Pre-training evaluation-1 & evaluation-2)

Phase IV: Training

Phase V: Post-Training evaluation (Post-training evaluation-1 & evaluation-2).

3.1 Participants

Forty-nine native speakers of Kannada, 39 aged between 55 to 64;11 years and 10 aged between 65 to 74;11 years were recruited for the study. Among the 49 participants, 23 participants who met the requirements of the study and were willing to undergo temporal resolution training were selected. Out of these 23 participants, 3 discontinued.

The 20 individuals who participated throughout the study were categorised into two age groups. Group I contained 13 individuals (5 males & 8 females) aged 55 to 64;11 years (mean age = 59.77 years; median age = 59 years; SD = 2.86 years). Group II had 7 participants (6 males & 1 female) aged 65 to 74;11 years (mean age = 67.57 years; median age = 68 years; SD = 2.22 years). Demographic data of these 20 participants is given in Table 3.1. Participants above the age of 55 years were selected since, it has been reported that auditory processing deficits exists in individuals above this age (Golding, Carter, Mitchell, & Hood, 2004). The participants met the following inclusion criteria:

- Hearing thresholds of ≤ 20 dB from 250 to 2000 Hz,
- Normal middle ear functioning, as determined through immittance evaluation,
- Presence of transient evoked otoacoustic emissions,
- Speech identification scores of at least 60% in quiet, indicating the presence of moderate difficulty in speech identification according to Goetzinger (1978),
- Score of ≥ 24 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975),
- Presence of auditory processing difficulties, as indicated on Screening Checklist for Auditory Processing in Adults (Vaidyanath & Yathiraj, 2014b),
- Deficits in temporal resolution and / or temporal ordering, based on the results of Gap-In-Noise test, Gap detection test and Duration pattern test,
- Minimum education level of 7th grade pass,
- Fluent speakers of Kannada, a language spoken in Southern India,
- No report of otological or neurological problems, and
- No history of speech and language problems.

Table 3.1
Demographic data of 20 participants who underwent training

Participant	**Age (yrs)**	**Gender**	**Score on MMSE**	**Score on SCAP-A**	**Presence of Hearing loss beyond 2000 Hz**	
					Right ear	**Left ear**
1	63	Female	26	4	No	No
2	68	Male	25	4	Yes	Yes
3	58	Female	28	2	Yes	Yes
4	56	Female	29	2	No	Yes
5	57	Female	30	5	No	Yes
6	65	Female	30	5	No	No
7	63	Female	27	1	Yes	Yes
8	64	Male	29	7	Yes	Yes
9	59	Female	27	2	No	No
10	70	Male	29	2	Yes	Yes
11	58	Female	29	2	No	No
12	56	Female	25	3	No	No
13	61	Male	28	4	Yes	Yes
14	58	Male	29	4	Yes	No
15	63	Male	30	10	No	Yes
16	61	Male	28	5	Yes	Yes
17	65	Male	29	3	Yes	Yes
18	66	Male	30	9	Yes	Yes
19	70	Male	29	5	Yes	Yes
20	69	Male	26	5	Yes	Yes

Note. Maximum possible score on MMSE = 30;
Maximum possible score on SCAP-A = 12;
Variations in thresholds between left and right ears ≤ 20 dB.

3.2 Instrumentation

The below mentioned equipment were used to carry out the study:

- A calibrated dual channel diagnostic audiometer (Madsen Astera) with TDH-39 headphones, B-71 bone vibrator and facility to route recorded audio signals through an auxiliary input, was used to select the participants and present the recorded test material,
- A calibrated immittance meter (GSI-TympStar, Version 2) was used to rule out the presence of middle ear pathology,
- An otoacoustic emissions analyzer (ILO V6) was employed to confirm the status of hearing,
- Using a four channel auditory evoked potential system (IHS Smart EP), auditory cortical evoked potentials were recorded,
- A personal computer (Compaq 610, with Intel Core 2 Duo processor and 3 GB RAM), was utilised to develop and play the recorded auditory evaluation and training material.

All equipments that required calibration were calibrated regularly throughout the period of data collection. The calibration for the audiometer was done as per the guidelines of ANSI S3.6 (2004) once in 3 months. The output stimuli from the auditory evoked potential system were calibrated before the commencement of the data collection of the study. The otoacoustic emission analyzer and the immittance meter were calibrated once in every 6 months.

3.3 Test environment

All audiological evaluations were carried out in an air-conditioned acoustically treated double room that met the specifications of ANSI S3.1 (1999). The training was carried out in quiet rooms, free from visual disturbances.

3.4 Material

3.4.1 Material for assessment.

The below mentioned material were employed for the study. In the absence of existing standard material, tests were developed as a part of the study.

- Edinburgh handedness inventory (Oldfield, 1971)
- Phonemically balanced word identification test in Kannada developed by (Yathiraj & Vijayalakshmi, 2005),
- Gap Detection Test (Shivaprakash, 2003),
- Gap-in-Noise Test (Musiek et al., 2005),
- Duration pattern test (Musiek, 1994; Musiek, Baran, & Pinheiro, 1990); norms developed by (Gauri, 2003),
- Dichotic CV test having 0 ms lag (Yathiraj, 1999),
- Speech-Perception-in-Noise test in Kannada (SPIN-K, developed as part of the current study),
- Voicing discrimination word test in Kannada (developed as part of the current study),
- Kannada Auditory Memory and Sequencing Test (Yathiraj & Vijayalakshmi, 2006),

- CVs /ṭa/ and /ḍa/ audio-recorded by Avilala and Yathiraj (2010), to obtain cortical evoked potentials / Mismatch Negativity (MMN).

The above auditory-based tests were selected as research studies have shown that the auditory perceptual abilities / auditory processes / higher cognitive abilities tapped by these tests are affected in older adults. The auditory processes found to be affected include temporal resolution (He et al., 1999; John et al., 2012; Schneider et al., 1994; Snell, 1997; Vaidyanath & Yathiraj, 2015), temporal ordering / sequencing (Fink et al., 2005; Fitzgibbons & Gordon-Salant, 1998; Trainor & Trehub, 1989), binaural integration (Gelfand et al., 1980; Jerger et al., 1994; Roup et al., 2006), and auditory separation / closure (Gelfand et al., 1986; Prosser et al., 1991; Russo & Pichora-Fuller, 2008). Similarly, voicing discrimination has also been found to be affected in older individuals (Price & Simon, 1984; Strouse et al., 1998; Tremblay et al., 2002). In addition, auditory memory has also been found to be affected in older adults (Grady & Craik, 2000; Old & Naveh-Benjamin, 2008). MMN was evaluated as studies have found a good correlation between it and behavioural discrimination (Kraus, Koch, McGee, Nicol, & Cunningham, 1999; Pakarinen, Takegata, Rinne, Huotilainen, & Näätänen, 2007). Likewise, LLR was chosen as research has shown that this can serve as an objective indicator of changes that occur in auditory perception consequent to auditory training (Tremblay et al., 2001; Tremblay, Ross, Inoue, McClannahan, & Collet, 2014).

3.4.2 Material for training.

The Auditory Temporal Resolution Training (ATRT) programme was developed as part of current study. This mainly focussed on improving gap detection abilities in the older adults.

3.5 Phase I: Development of material:

In the present study, 2 tests were developed for evaluation [Speech-perception-in-noise test in Kannada (SPIN-K) & Voicing discrimination word test in Kannada (VDWT)]. Additionally, material for training was also developed.

3.5.1 Development of Speech-perception-in-noise test in Kannada (SPIN-K).

To assess auditory separation / closure, Kannada words in the presence of 8-speaker speech babble was developed. The stimuli used were words from the ‘Phonemically balanced word identification test in Kannada’. The speech babble in Kannada was developed as a part of the current study.

The Kannada articulation test (Babu, Ratna, & Bettagiri, 1972) that contained a passage (part 4 of the test) having all the phoneme of Kannada was selected to create the speech babble. Recordings of the diagnostic test by 8 fluent speakers of Kannada (4 males & 4 females) were done independently. To record the material, Computerized Speech Lab Model 4500 software with a Shure dynamic microphone, placed 10 cm away from the mouth of the talker, was used. The 8 independent recordings of the passage were digitally mixed using the Adobe Audition 3 (Version 3.0.1) software to obtain a single wave file. From the speech babble generated, multiple noise segments having durations of 800 ms, 900 ms, or 1200 ms were obtained. It was ensured that all the noise segments had constant amplitude with no silence. The duration of the noise segment for a particular stimulus was selected depended on the duration of the word. For words having a duration within 600 ms, a noise segment of 800 ms was used while for words having a duration between 600 to 700 ms, a noise segment of 900 ms was used. For words with a duration greater than 700 ms, a 1200 ms noise segment was utilized. The speech signal was placed in the centre of the noise segment such that equal duration of noise was present before and after the onset / offset of the words. The intensity level of the noise segments and words were made similar using the Adobe Audition software (Version CS5.5). The speech signal was inserted in one track and the noise segments in another to form a single waveform containing both speech and noise. An interval of 4 s was inserted between successive stimuli. Four lists, with 25 words in each list, were prepared. A 1 kHz calibration tone having a duration of 8 s was inserted at the beginning of the test.

To ensure that the recording was clear and to check for the reliability of the developed test, it was administered on 10 normal hearing individuals who had Kannada as their native language. These participants, aged 18 to 30 years, obtained an average score of 20 out of the 25 words presented in the presence of noise, which was similar to the speech-in-noise scores reported by Kalikow, Stevens, and Elliott (1977).

3.5.2 Development of Voicing discrimination word test in Kannada.

The ‘Voicing discrimination word test in Kannada’ was developed using meaningful bi-syllabic and tri-syllabic words selected from a Kannada dictionary. Using the selected words, 150 minimal pairs were made that differed only in voicing. After randomizing the words, the familiarity of each word was individually assessed using a three point rating scale (highly familiar, familiar, & unfamiliar). Words were rated as ‘highly familiar’ if they were considered to occur between 75-100% of the time in daily usage and the meaning was known. Words were rated as ‘familiar’ if they were thought to occur between 50-75% of the time in daily usage and the meaning was known.

‘Unfamiliar words’ were those that occurred less than 50% of the time in daily usage and the meaning was not known. The familiarity of the material was evaluated by 10 Kannada speaking individuals in the age range of 55 to 75 years and 10 children studying in the 8th grade in schools having Kannada as the medium of instruction. Only the words that were rated as highly familiar or familiar were shortlisted to form the test. Four word-lists were prepared, each containing 30 word-pairs. The four lists were equated in terms of the number of phonemes, familiarity level of the words, and frequency of occurrence of the phonemes in Kannada language, as given by Sreedevi (2013). It was ensured that each contrastive phoneme of the minimal pairs (e.g./ka/-/ga/) was represented equal number of times in the four lists in the initial as well as medial position of the words. As consonants do not occur in the final position of words in Kannada, this word position was not included.

A native Kannada female speaker recorded the minimal word-pairs using Computerized Speech Lab Model 4500 software with a Shure dynamic microphone placed 10 cm away from the mouth. The recording was done using a sampling frequency of 44100 Hz and 16-bit resolution. Adobe Audition 3 (Version 3.0.1) software was used to normalise the recoded speech material to ensure that they had similar intensity. Within a word-pair, an interval of 500 ms was maintained while between word-pairs an interval of 4 s was inserted. A 1 kHz calibration tone of 8 s was inserted at the beginning of the word lists. A goodness test of the recorded stimuli was carried out on 10 native speakers of the language. Words judged unintelligible were re-recorded.

3.5.3 Development of Auditory Temporal Resolution Training (ATRT) programme material.

The stimuli for the ATRT programme had segments of broadband noise and narrow band noise with silent gaps embedded within them, generated using Adobe Audition 3 (Version 3.0.1). The narrow band noise segments were generated from white noise segments that were one-third octave band filtered to obtain noise segments with centre frequencies of 500 Hz, 1000 Hz, and 2000 Hz. Two different durations of noise segments were generated (300 ms & 200 ms) to vary the complexity of the training material, as gap detection is reported to depend on the duration of the noise segment (Pichora-Fuller et al., 2006). Gaps that varied in durations from 30 ms to 3 ms were inserted at the centre of the noise segments. The entire auditory temporal resolution training material was divided into four levels (Level I to Level IV) to form a hierarchy of activities that varied in terms of the duration of the noise segments, the duration of the gap as well as the number of alternatives from which the responses are to be selected. All four levels involved discrimination tasks, with the participants having to indicate which stimulus within a set contained a gap. Depending on the level, a set contained two, three or 4 alternatives (sequences), with one stimulus-alternative in a set having a gap. Within a level, the duration of gap reduced from one set to the next in order to increase the difficulty of the task. In each level, the stimuli were presented 10 times in a cyclic manner. Within a cycle of presentation, each gap duration was presented only once, commencing with the largest gap and gradually proceeding to the smallest gap. Thus, each cycle was presented in a similar manner 10 times in each level.

Level I in the auditory temporal resolution training programme material consisted of 6 sets of 300 ms stimuli with gap durations varying from 30 ms to 20 ms embedded in broadband and the narrow band noise segments. The stimuli in level I was presented in pairs (2-stimuli sequence) with one stimulus of a pair containing a gap and the other containing no gap. Screenshot of the APEX 3 software stimulus presentation is shown in Figures 3.1. The order of the stimulus in which the gap occurred was randomised within and between the various sets. In this level, the gap duration decreased in steps of 2 ms from one set to the other. Each stimulus-set was presented 10 times making the total number of presentations 60 for each of the four noise types (BBN, 500 Hz NBN, 1000 Hz NBN and 2000 Hz NBN).

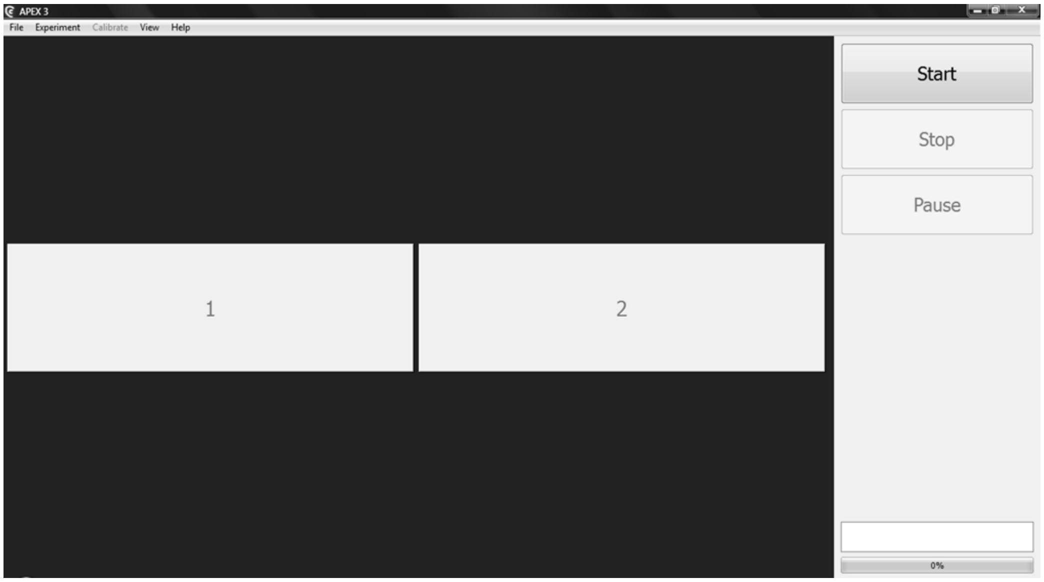
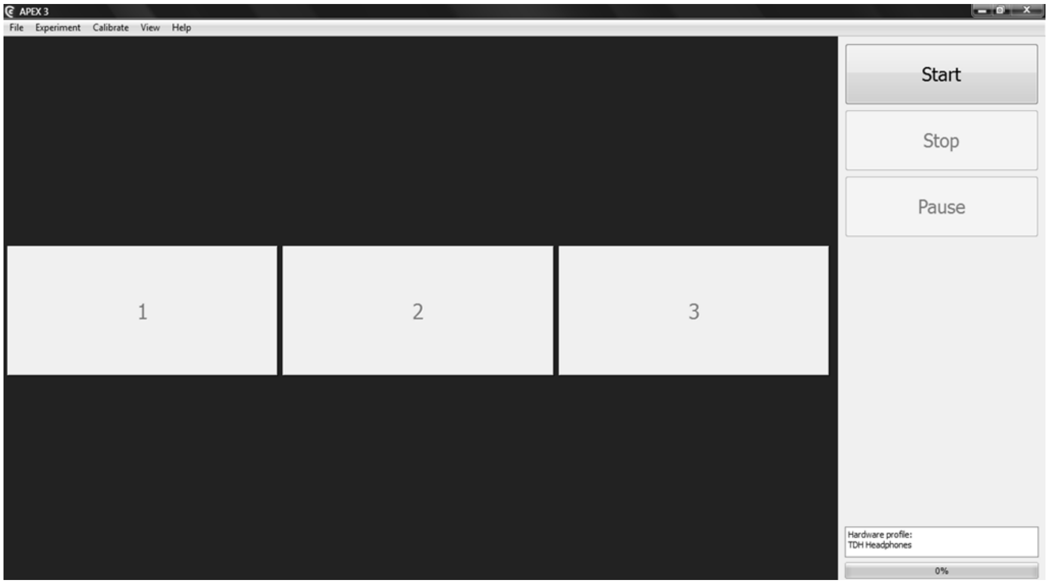


Figure 3.1 Screenshot of the software used for stimulus presentation in Levels I and II.

Level II, like level I, consisted of 6 stimulus-sets having 2-stimuli sequences. Each set, having different durations of gaps, was presented 10 times. Thus, each type of noise had a total of 60 presentations. In addition, similar to level I, the duration of the gap from one set to next reduced in 2 ms gaps. However, the duration of the noise segments and the duration of the gaps within the noise were lesser compared to level I. While the duration of the noise was reduced to 200 ms, the duration of the gaps embedded in the noise varied from 20 ms to 10 ms.

Level III contained 3-stimuli sequence with 11 stimulus-sets. Similar to the other levels, each stimulus-set had different durations of gaps. As each set was repeated 10 times, each of the four noise types had 110 stimuli presentations. The duration of the noise bursts was 200 ms with gaps of 16 ms to 3 ms duration embedded in them. One stimulus out of the three presented in a sequence contained the gap. From one set to the next, the duration of the gaps reduced by 2 ms for the first 4 sets and by 1 ms for the remaining 8 sets. Screenshot of the APEX 3 software stimulus presentation at Level III is shown in Figure 3.2.



Hardware profile:
TDH Headphones

Figure 3.2. Screenshot of the software used for stimulus presentation in Level III.

Level IV of the hierarchy consisted of 8 stimulus-sets presented in a 4-stimuli sequence. Each stimulus-set had 10 presentations for each of the 4 types of noise bursts.

Thus, each noise type had 80 presentations. The noise bursts had a duration of 200 ms with 10 ms to 3 ms gaps embedded within them. One stimulus among the four that were presented contained a gap. Screenshot of the APEX 3 software stimulus presentation is shown in Figure 3.3. The gaps were decreased by 1 ms from one stimulus-set to the next. A flowchart of the stimuli used in each of the levels for training is provided in Figure 3.4. Details of the instructions, training material and scoring are provided in Appendix I.

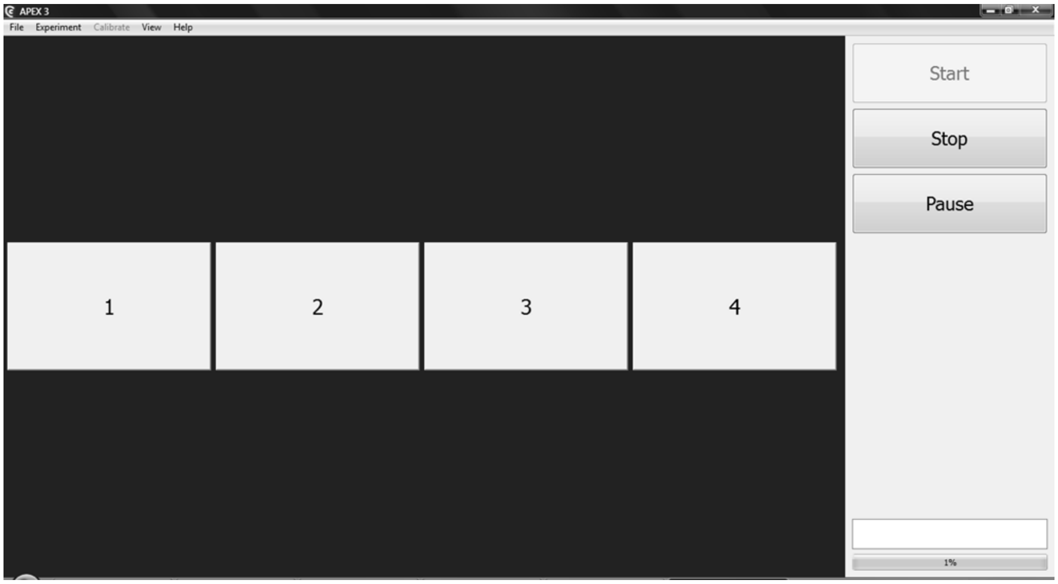


Figure 3.3. Screenshot of the software used for stimulus presentation in Level IV.

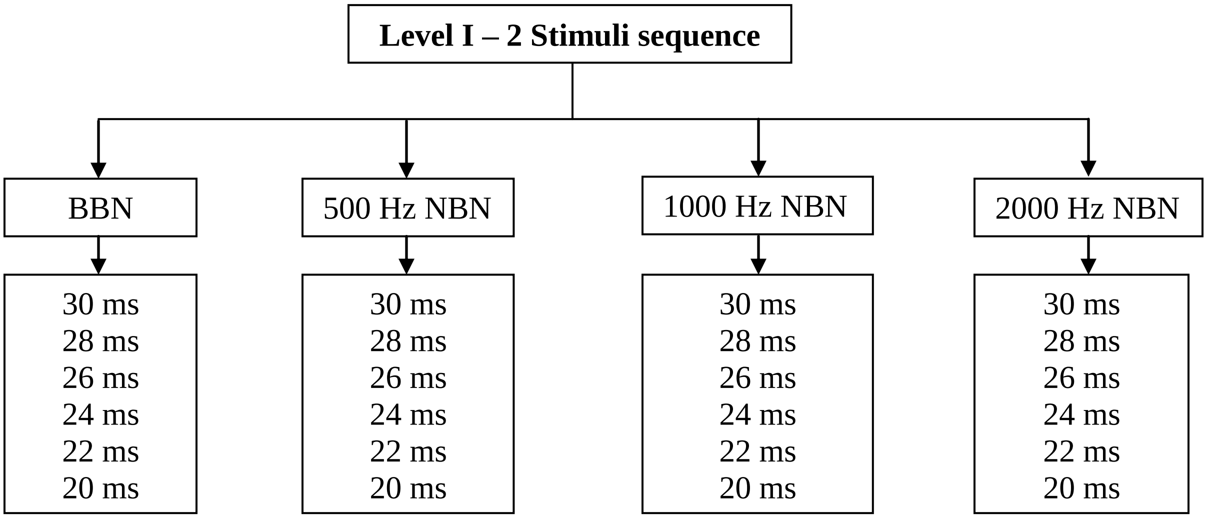
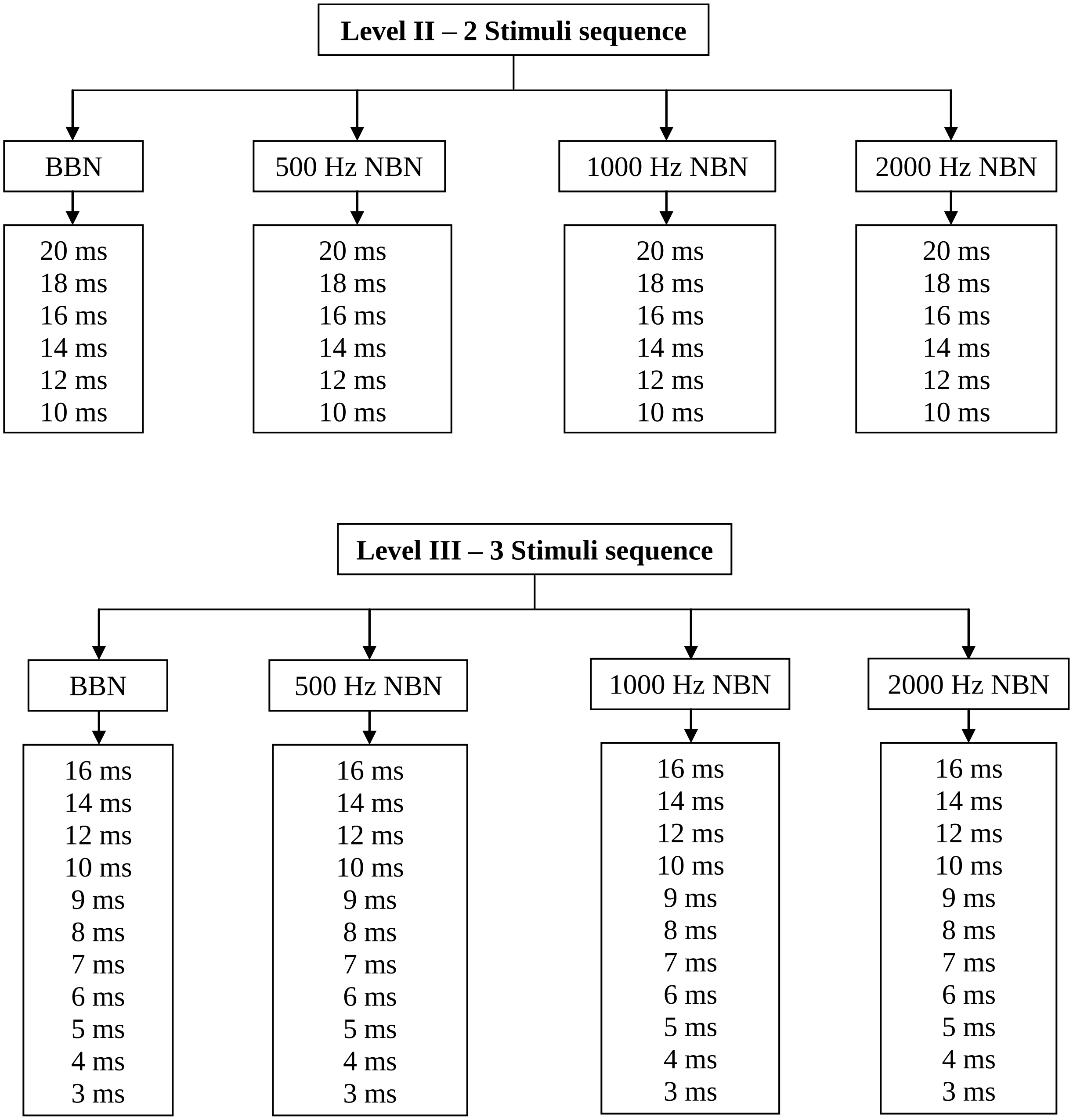


Figure 3.4 continued…



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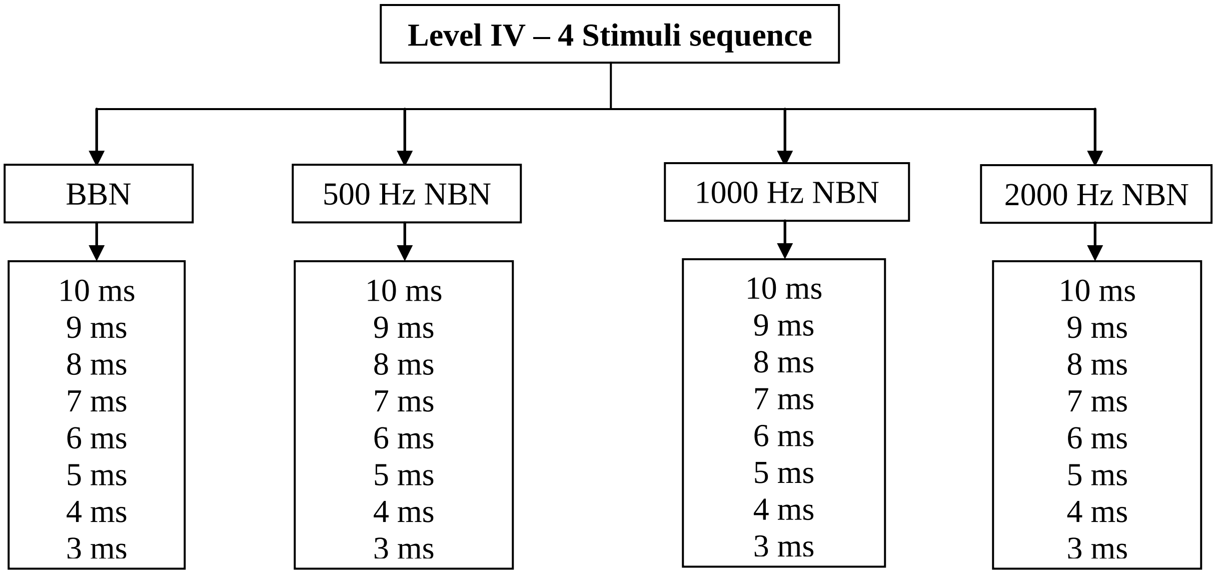


Figure 3.4. Flowchart depicting the 4 levels of the Auditory Temporal Resolution Training programme

The noise segments used for the training material were presented using APEX 3 software (Francart, Van Wieringen, & Wouters, 2008). The software was also used to obtain the responses from the participants after demonstrating what they were expected to do. The APEX 3 software programme was designed such that, each of the gap durations was presented 10 times in a session. The inter-stimulus interval in a stimulus-set was fixed at 500 ms. Provision was made for a visual feedback to be given after each response from the participants. The feedback, provided for 300 ms, consisted of a 'thumbs up' sign for a correct response and a 'thumbs down' sign for a wrong response. The 'result-viewer' of the APEX 3 software was designed to display the stimulus presented, the correct option / answer, the answer provided by the participants, the decision whether the answer provided was correct or wrong and the total percentage of correct identifications. After the ATRT programme was developed, it was administered on 5 young adults with normal hearing to see if they were able to carry out the tasks in all four levels. All the 5 young adults were easily able to carry out the task and obtained 100% scores on all the four noise types used in each level.

3.6 Procedure

Initially, evaluation was carried out to select the participants for the study to ensure that they met the inclusion criteria. Those who met the inclusion criteria were evaluated on the auditory perceptual tests / auditory processes / higher cognitive abilities prior to and following training. Details of the procedure used to select and determine auditory perception / processing abilities are described in Phase II and Phase III respectively.

3.6.1 Phase II: Procedure for selection of participants

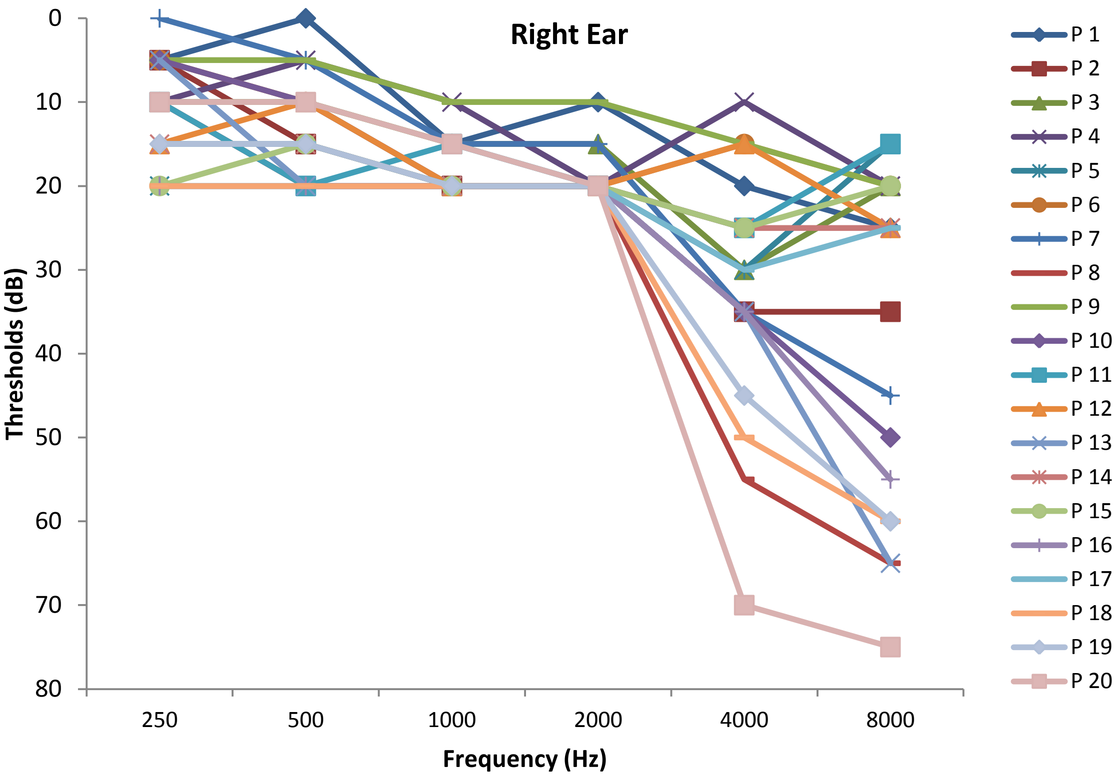
Prior to the commencement of data collection, the method of the study was approved by the AIISH ethical committee for bio-behavioural research. Further, written consent was obtained from the participants, as required by the 'Ethical guidelines for Bio-behavioural research involving human subjects' (All India Institute of Speech and Hearing, 2009).

To ensure that all the participants met the inclusion criteria of the study, relevant information was obtained from them or family members as well as they were subjected to various tests. The section below describes the information obtained / tests administered on the participants.

A case history was obtained to acquire any relevant past information related to their hearing abilities. The information was obtained from the participant and / or the family regarding the presence of a hearing loss, family history of hearing loss, history of exposure to loud noise, history of ear infections / surgery, use of ototoxic drugs, presence of systemic diseases (hypertension and diabetes), and exposure to music. Those older individuals who did not report of a hearing loss, history of exposure to loud noise, history of ear infections / surgery, and the use of ototoxic drugs were subjected to further investigation for inclusion into the study.

Pure-tone air conduction and bone conduction thresholds were obtained using the modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Air conduction and bone conduction thresholds were established for octave frequencies between 250 to 8000 Hz and 250 to 4000 Hz respectively. Those older individuals with pure-tone thresholds ≤ 20 dB HL binaurally between the frequencies of 250 to 2000 Hz were included for further evaluation. Figure 3.5 depicts the pure-tone thresholds of the 20 participants who were later selected for the study.

Speech Reception Thresholds were measured using paired-words in Kannada developed at the Department of Audiology, AIISH, Mysuru. The paired words were presented at 20 dB SL (*ref:* PTA) and the intensity level was reduced until two out of three paired words were correctly repeated. This served as the reference intensity for other supra-threshold speech tests that were performed.



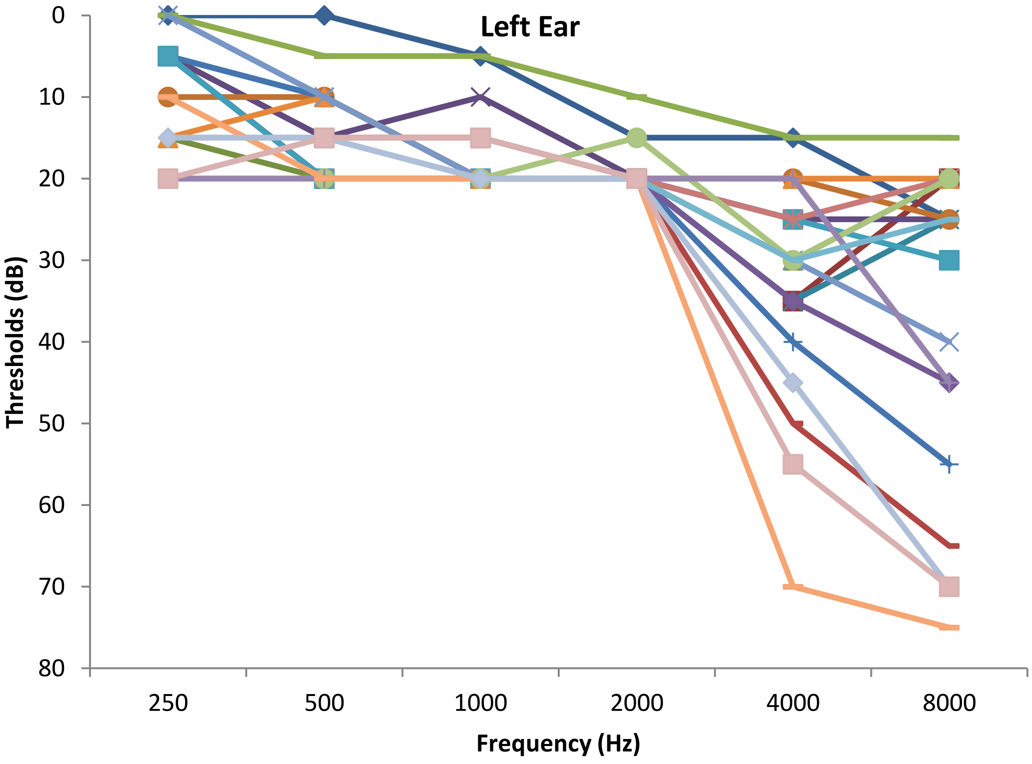


Figure 3.5. Pure-tone thresholds for the two ears of 20 participants who underwent training.

Speech Identification Scores (SIS) were measured using the phonemically balanced word identification test in Kannada (Yathiraj & Vijayalakshmi, 2005). The recorded words were presented at 40 dB SL (*ref: SRT*). The total percentage of words correctly identified, was considered as the SIS. Although the participant selection criteria was to select older individuals with at least 60% scores, it was found that they had speech identification scores ranging from 92% to 100%.

Middle ear function was tested using a calibrated immittance meter. Tympanogram was obtained with a 226 Hz probe tone. Ipsilateral and contralateral reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Those older adults with immittance audiometry indicating normal middle ear function were selected for the study.

Click evoked transient otoacoustic emissions were measured to ensure the absence of any cochlear pathology. The click stimuli were presented at 85 dB SPL. TOAEs were considered present when the amplitude of the responses was 3 dB above the noise floor. Only those with TOAEs presented were included in the study.

The Mini Mental State Examination (Folstein et al., 1975), translated by Shobha et al. (2011) to Kannada was administered. This was used to rule out the presence of any cognitive deficits in the older adults. Those older individuals who obtained a score ≥ 24, indicating normal cognitive functioning, were considered for further evaluation.

The *Screening Checklist for Auditory Processing in Adults (SCAP-A)* was administered on the older adults to obtain information about the presence of an auditory processing deficit. Older adults who indicated positive symptoms were included. Since at the time of data collection the validation of the screening checklist was not completed, individuals with any positive symptom were included in the study.

Forty-nine older individuals who met the above inclusion criteria were evaluated further to confirm the presence of a temporal processing problem using Gap-In-Noise test, Gap Detection Test, and Duration Pattern Test. These temporal processing tests also served as part of the baseline evaluation (pre-training evaluation-1) and are described in Phase III of the method.

Based on the results of the above-mentioned tests, 23 participants who were willing to attend the 'auditory temporal resolution training programme' were selected. These participants were recruited for phases III, IV, and V of the study.

3.6.2 Phase III: Procedure for pre-training baseline evaluations: (Pre-training evaluation-1 & Pre-training evaluation-2)

The pre-training baseline evaluations included the administration of both behavioural and electrophysiological tests. Two behavioural pre-training evaluations were conducted with the second evaluation (pre-training evaluation-2) being administered after a minimum gap of 2 weeks after the first evaluation (pre-training evaluation-1). It was ascertained that the participants did not undergo any intervention procedure during the intervening period. The purpose of the second baseline evaluation was to determine if any changes occurred on the specific measures being evaluated without any intervention.

3.6.2.1 Behavioural tests.

The participants were evaluated using seven behavioural tests prior to the initiation of the training. These tests included Gap-In-Noise test, Gap Detection Test, Duration Pattern test, Dichotic CV test, Speech-Perception-in-Noise test in Kannada, Voicing discrimination word test in Kannada, and Kannada auditory memory and sequencing test. Two tests of temporal resolution (GDT & GIN) were utilized as Vaidyanath and Yathiraj (2015) reported that these two tests assessed different aspects of temporal resolution.

All the behavioural tests were administered twice to obtain the two baseline evaluations. The two baseline evaluations served to prove the test-retest reliability of the tests. However, the order of the tests was randomized to avoid any test order effect. Additionally, half the participants were tested in the right ear first and half in the left ear first to eliminated an ear order effect for those tests that required monotic evaluation. This was done at each of the evaluations. Further, equivalent lists of the tests were used to avoid familiarity of the material influencing the test results. It was ensured that the same list of each test was not administered on the individuals on two consecutive evaluations.

Prior to the initiation of the tests, the VU meter deflection was adjusted to zero using the 1 kHz calibration tone provided for the tests. In addition, practice trials were presented to all participants, when available in the test. The presentation levels used in all the tests were as per the recommendations of the original tests. Details of the behavioural tests administered are described below.

The *Gap-In-Noise test (GIN)* (Musiek et al., 2005) was administered under headphones for each ear separately. The output of the CD version of the test, played on a computer, was routed through an audiometer and presented at 50 dB SL (*ref. PTA*). The participants were instructed to press a response button as soon they heard a gap embedded in a 6 s noise segment. Each gap duration was presented six times, randomly within each list. The minimum duration of gap that was correctly identified at least four out of the six presentations was considered as the approximate gap detection threshold (term given by Musiek et. al). Prior to the evaluation, a practice trial was given to all the participants to ensure that the instructions were correctly understood and that they were able to respond using a response button. To consider a person pass or fail on GIN, the norms given by Aravindkumar et al. (2012) for young adults was used.

The CD version of the *Gap Detection Test (GDT)* developed by Shivaprakash (2003), played using a computer, was routed through an audiometer and presented at 40 dB SL (*ref. PTA*) through headphones to each ear individually. The test consists of sets of three bursts of white noise, each having duration of 300 ms. One of the noise-bursts had a gap embedded. The participants were instructed to indicate which of the three noise-bursts contained the gap. The minimum gap duration that could be detected was considered as the gap detection threshold. The norms for young adults, given by Shivaprakash were used to categorise the individuals as pass or fail on the test.

The *Duration Pattern Test (DPT)* developed by Musiek, Baran, et al. (1990) with the norms of Gauri (2003) was used to assess temporal ordering abilities. The CD version of the test was played through a computer, the output of which was routed to the auxiliary input of an audiometer. The evaluations were carried out under headphones with the signal presented at 40 dB SL (*ref. SRT*). Each correct response was given a score 1 and 0 for an incorrect response with the maximum possible score of 30. Each ear was assessed separately.

The *Dichotic CV* test, re-recorded by Yathiraj (1999), was used to assess binaural integration abilities. The stimuli from the CD version of the test were presented through an audiometer to headphones at 40 dB SL (*ref. SRT*). The stimuli consisted of 6 CVs /pa, ṭa, ka, ba, ḍa, ga/. The participants were instructed to repeat the two CVs heard simultaneously, irrespective of the ear in which they heard them. Single correct and double correct responses were scored. For the former, the responses from each ear were scored separately, with each correct response being given a score of 1. For the latter, a score of 1 was given only when the responses from both ears were correctly identified. The maximum possible score was 30 for each of the single correct scores as well as for the double correct scores. The norms of Prachi (2000) were used to judge if an individual passed or failed the test.

The monaural auditory separation / closure ability was assessed using the *Speech-Perception-in-Noise Test in Kannada (SPIN-K)* that was developed as part of the study. The stimuli consisted of phonemically balanced words presented in the presence of ipsilateral 8-speaker babble. The stimuli were presented at 40 dB SL (*ref. SRT*) at 0 dB SNR through an audiometer and were heard by the participants via headphones. Each word repeated correctly was assigned a score of 1 and a score of 0 was given for each incorrect response. The maximum possible score was 25. The responses for each ear were scored separately. The total number of words correctly identified was noted.

Discrimination of voicing was assessed using the *Voicing discrimination word test in Kannada*, developed in the current study. The recorded list of minimal pairs were presented at 40 dB SL (*ref: SRT*) through headphones via an audiometer. Each ear was evaluated separately. The participants were instructed to judge whether the two words presented were same or different. A score of ‘1’ was awarded for every correct response and a score of ‘0’ for every incorrect response. The total score obtained was noted. The maximum possible score for each list was 30.

The *Kannada Auditory Memory and Sequencing Test*, developed by Yathiraj and Vijayalakshmi (2006) was used to assess auditory memory abilities. The test was administered with the modified scoring procedure recommended by (Vaidyanath & Yathiraj, 2014a). The stimuli consisted of sequences of words commencing from 3-word sequences and progressed up to 8-word sequences. The 3- and 4-word sequences consisted of two tokens each and the 5-, 6- 7- and 8-word sequences consisted of 4 tokens each. Via an audiometer, the stimuli were presented at 40 dB SL (*ref. SRT*) through headphones binaurally. From the verbal responses of the participants, auditory memory span and auditory sequencing span were calculated. Auditory memory span was calculated by determining the longest word sequence in which 50% of the tokens were correctly recalled. Likewise, auditory sequencing span was calculated as the longest word sequence in which 50% of the tokens were recalled in the correct order.

3.6.2.2 Electrophysiological tests.

Mismatch Negativity (MMN) and Long Latency Responses (LLR) were used to assess cortical processing. MMN was recorded for the stimuli /ṭa/ and /ḍa/ as this unvoiced-voiced stimulus pair has been noted to elicit enhanced MMN responses by

Sharma and Dorman (1999). MMN has also been reported to be an index of auditory discrimination (Kraus et al., 1995) and hence was used to evaluate effects of discrimination training. Using the same stimuli as that used to measure MMN (/ṭa/ & /ḍa/), two separate LLRs were recorded for each participant. These stimuli were chosen as studies using MMN have observed that children with learning disabilities have more difficulty perceiving them compared to other combination of phonemes (Brandt & Rosen, 1980; Werker & Tees, 1987). Additionally, this pair was selected due to the temporal difference in the two stimuli. The waveforms and spectrograms of the two CVs /ṭa/ and /ḍa/ are shown in Figure 3.7 and Figure 3.6 respectively.

MMN and LLR were recorded while the participants were seated comfortably on a reclining chair. They were encouraged to watch a silent, subtitled movie, after being instructed to ignore the stimuli presented to the right ear. As studies have shown that the left hemisphere codes temporal related information better than the right hemisphere (Liégeois-Chauvel et al., 1999; Okamoto, Stracke, Draganova, & Pantev, 2009; Zatorre & Belin, 2001), the right ear was chosen for evaluation. The stimulus and recording parameters given in Table 3.2 were used to obtain the MMN and LLR.

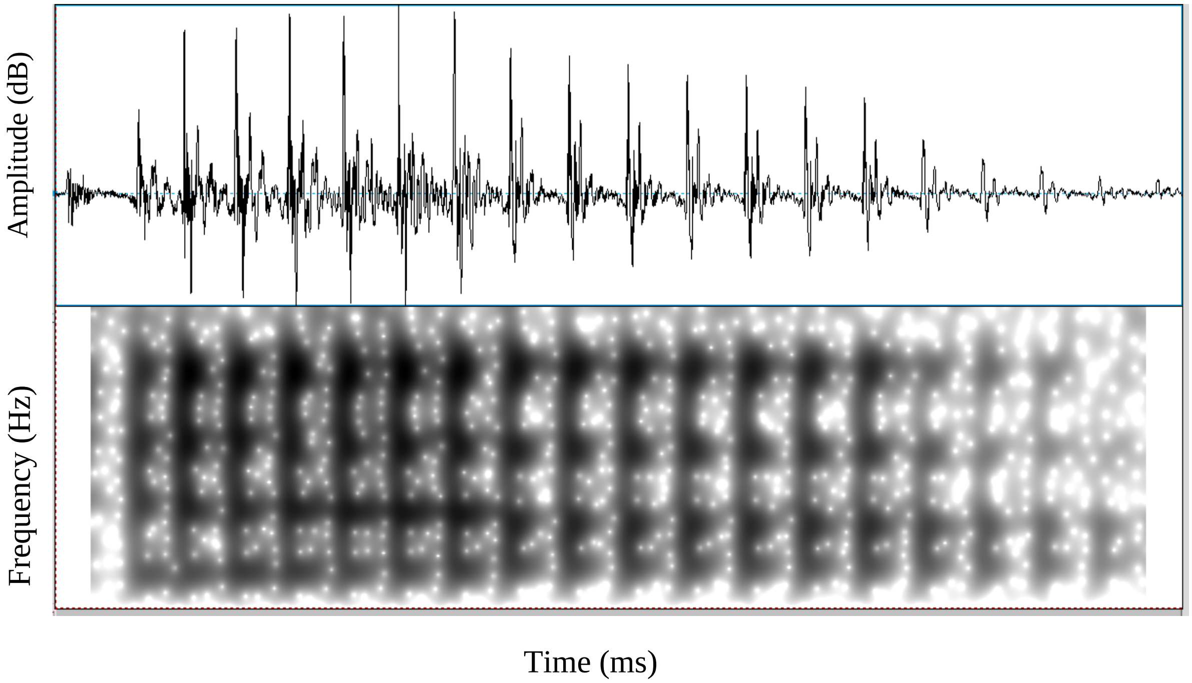


Figure 3.6. Waveform and spectrogram of /ṭa/ stimuli used in MMN and LLR recording.

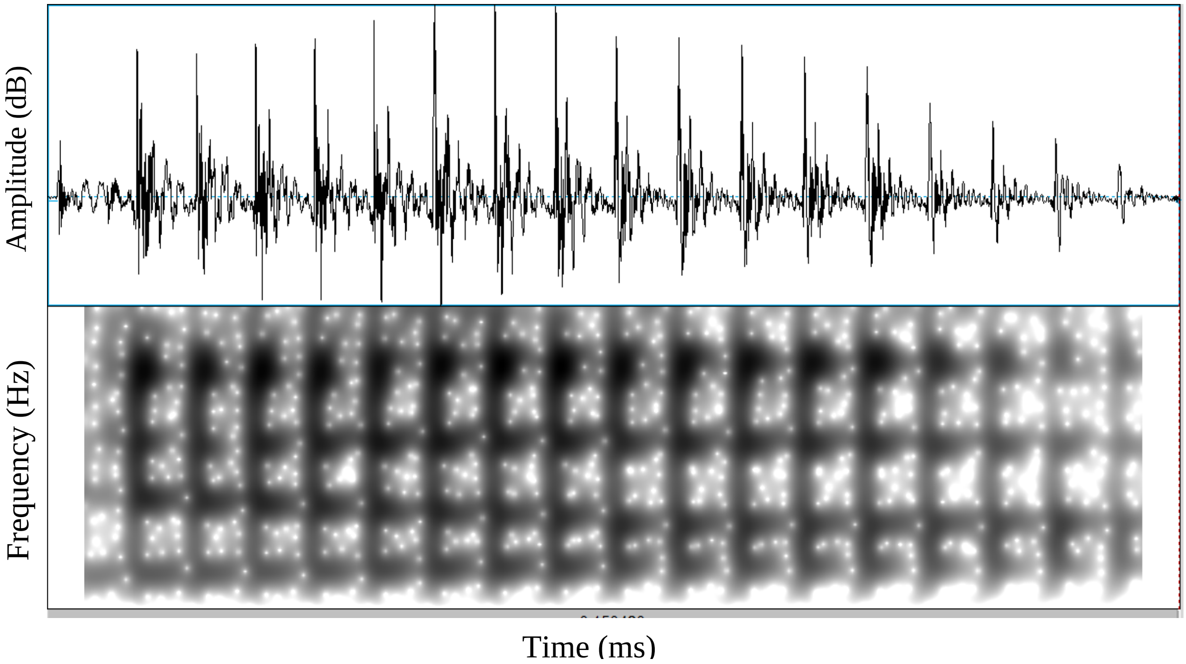


Figure 3.7. Waveform and spectrogram of /ḍa/ stimuli used in MMN and LLR recording.

Table 3.2

Stimulus and recording parameters to obtain MMN and LLR

Parameter	**MMN**	**LLR**
Stimuli	Monosyllables: Frequent: /ṭa/ Infrequent: /ḍa/	Monosyllables: /ṭa/ and /ḍa/
Intensity	(75 dB SPL)	(75 dB SPL)
Duration of stimuli	150 ms	150 ms
Maximum number of averages	200 for infrequent stimuli	200
Repetition rate	1.1/s	1.1/s
Ratio of frequent to infrequent stimuli	5:1	NA
Number of channels	4	4
Gain	50000	50000
Electrode Montage	Cz to nose tip F3 to nose tip F4 to nose tip (connected through a jumper) Ocular: Supraorbital and infraorbital electrodes around left eye Common: Mastoid	Cz to nose tip F3 to nose tip F4 to nose tip (connected through a jumper) Ocular: Supraorbital and infraorbital electrodes around left eye Common: Mastoid
Band-pass filter	1 to 30 Hz	1 to 30 Hz
Recording window	-50 to 512 ms	-50 to 512 ms
Transducer	ER-3A insert earphones	ER-3A insert earphones
Artifact rejection	≥ 50µv	50µv
Ear of stimulation	Right	Right

MMN and LLR were recorded only in pre-training evaluation-2 and not during pre-training evaluation-1. The electrophysiological evaluation was done during the first evaluation to avoid having attrition of the participants who would have been discouraged from participating due to the long test duration.

MMN was recorded twice, once with /ṭa/ as the frequent stimulus and /ḍa/ as the infrequent stimulus and once with /ṭa/ as the infrequent stimulus and /ḍa/ as the frequent stimulus. Likewise, LLR was recorded twice, once for each of the stimuli. The responses were initially analysed for the presence of MMN. Before doing the analysis of the MMN, wave forms were corrected for baseline EEG activity. The pre-stimulus electrical activity for 50 ms before the presentation of stimulus was subtracted from the whole waveform. As the MMN responses were obtained in only three older adults, these responses were not analysed and the latency and amplitude of only the LLR were analysed.

Three experienced audiologists, with more than 5 years of experience, independently analysed the cortical responses to prevent any tester bias. They were instructed to identify the latencies of the N1 and P2 peaks and the peak-to-peak amplitude of N1-P2 components of each LLR. The amplitude and latencies of these responses for /ṭa/ and /ḍa/ CV syllables at Cz, F3 and F4 were tabulated. A response was considered valid only if at least two out of the three audiologists identified the responses similarly.

3.6.3 Phase IV: Procedure for Training

The training for temporal resolution judgements was done for all participants using the material developed in the study. This was done by the experimenter in the homes of the participants. As far as possible, it was ensured that the level of ambient noise and visual distraction were similar. The material for training, loaded on a laptop computer, was presented via a Sinnheiser HDA 200 headphones binaurally using APEX-3 software. The output of the computer was calibrated using a Larson and Davis (824) sound level meter and NBS 9A 6 cc coupler, to ensure that the output level from the headphones was maintained at 70 dB SPL.

The training was initiated at Level I with stimuli having longer noise segments as well as longer gaps. The participants progressed to the next higher level only if they obtained at least 80% on a particular level across all the 4 stimulus types considered (BBN, 500 Hz NBN, 1000 Hz NBN, and 2000 Hz NBN). In each session, initially the stimulus with the longest gap duration in a particular level was presented. Following this, the gaps were gradually reduced in the subsequent presentations until the shortest gap duration in the level was reached.

Prior to the start of the training programme, the participants were briefed about its contents, the duration of each session and the approximate number of sessions. Additionally, they were instructed at each level that they would hear simultaneously in both ears (binaurally) bursts of noise with some stimuli having a gap embedded in them and others without any gap. At level I and II they were instructed that they would hear two stimuli and they were asked to click on the number of the stimuli / option, which had a gap embedded in them using the mouse of the computer (Figure 3.1). They were also informed that for each correct response a green coloured ‘thumbs up’ sign would appear on the screen. If their response was incorrect, a red coloured ‘thumbs down’ would appear on the screen and the correct stimuli interval would be highlighted. They were also informed that the next presentation would be heard only when a response was given. In case they were unsure about a response, the participants were asked to guess so that the training session could continue. Likewise, for levels III and IV they were told that they would have to choose among the 3 / 4 bursts of stimuli, respectively that they heard and select the appropriate response on the computer screen (Figures 3.2 & 3.3).

The participants received 1-hour training sessions every day until they met the criteria for termination of training. The number of training sessions each participant underwent varied (Figure 3.8), with it ranging from 7 to 13 (mean = 9.2 sessions; median = 9 sessions). At the end of each training session, the participants were shown the software generated report of their progress. This included the list of stimuli presented, the correct answer, the answer provided by the participant, decision whether the response is correct or not, and the total percentage of the gaps that were correctly identified. Depending on the score obtained, the decision to continue at the same level or to proceed to the next level was taken. If an improvement in the total percentage score was observed, then the training session was continued until the participant reached the 80% score and the next level was initiated. The next level was initiated only if the participants maintained a score of 80% or above in 3 consecutive sessions. The training was terminated when the responses reached the 80% criteria or the scores plateaued for 3 consecutive sessions at Level IV.

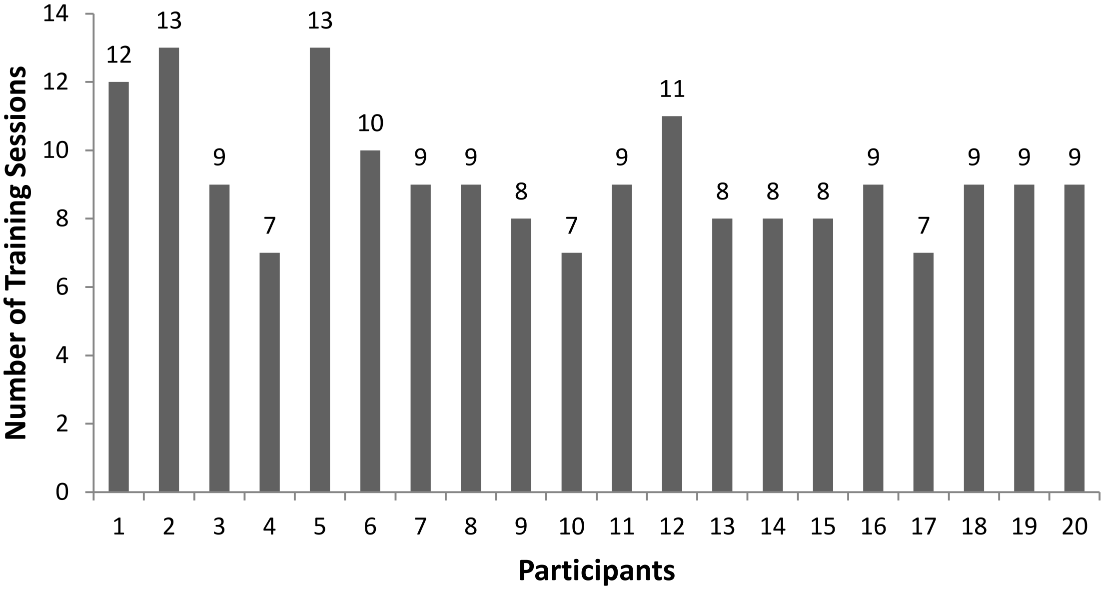


Figure 3.8. Number of training sessions received by each participant.

3.6.4 Phase V: Procedure for post-training assessment: Post-training evaluation-1 and Post-training evaluation-2

All the behavioural and the LLR evaluations done during the pre-training evaluations were repeated immediately after the termination of training (post-training evaluation-1). Additionally, four weeks following the cessation of training, a second post-training evaluation (post-training evaluation-2) was done to establish the maintenance of the learnt information. The post-training evaluation-2 could be carried out in only 50% of the individuals (10 individuals) who underwent temporal resolution training due to the participants' non-availability / unwillingness to participate further in the study.

3.7 Statistical analyses

The scores obtained in the two pre-training evaluations and the two post-training evaluations were analysed using descriptive and inferential statistics. The descriptive statistics including mean, median, and standard deviation that was obtained to compare the scores across the different evaluations. Shapiro-Wilk test was done to establish whether the participants were normally distributed. Mann-Whitney test was carried out to compare the performance of the two age groups. For the responses of tests that had normal distribution, a repeated measure ANOVA was done to compare the performance across the evaluations. For the responses of tests in which normal distribution was not found, Friedman and Wilcoxon tests were done.

Chapter 4

RESULTS

The data of the 20 participants who underwent the Auditory Temporal Resolution Training (ATRT) were analyzed to establish the difference between the two age groups (55 to 64;11 & 65 to 74;11 years) on the performance in tests of auditory processing, voicing discrimination and auditory memory. The effect of ATRT was obtained by comparing the performance on different tests (Gap-In-Noise, Gap Detection, Duration Pattern, Speech-Perception-in-Noise, Voicing discrimination word test in Kannada, & Auditory memory and sequencing) across the different evaluations (pre-training evaluations- 1 & 2, and post-training evaluations- 1 & 2). The results of these comparisons are presented under the following headings:

4.1 Effect of age on test performance (auditory processing, voicing discrimination, & auditory memory).

4.2 Comparison of performance on behavioural tests in pre-training evaluation-1 and pre-training evaluation-2.

4.3 Effect of temporal resolution training on the following test performance:

  4.3.1 Gap-In-Noise test.

  4.3.2 Gap Detection Test.

  4.3.3 Duration Pattern Test.

  4.3.4 Dichotic CV test.

4.3.5 Speech-Perception-in-Noise test in Kannada.

4.3.6 Voicing discrimination word test in Kannada.

4.3.7 Kannada auditory memory and sequencing test.

4.3.8 Phoneme error pattern in the presence of noise.

4.3.9 Speech evoked cortical responses.

4.1 Effect of age on auditory processing, voicing discrimination and auditory memory

The data obtained from 20 participants (11 males & 9 females), grouped into two age groups were compared to determine the effect of age on the performance on seven tests. These tests evaluated auditory processing (Gap-In-Noise test [GIN], Gap Detection Test [GDT], Duration Pattern Test [DPT], Dichotic CV test [DCV], Speech-Perception-in-Noise test in Kannada [SPIN-K]), voicing discrimination (Voicing Discrimination Word Test in Kannada [VDWT]) and auditory memory (Kannada Auditory Memory and Sequencing Test [KAMST]). Prior to comparing the variables, a Shapiro-Wilk test of normality was done to see if the two age groups were normally distributed. It was observed that for all tests except the DCV test both age groups did not follow normal distribution when they were evaluated independently as well as when combined (Table 4.1). Hence, non-parametric tests were used for comparisons across the two age groups for GIN, GDT, DPT, SPIN-K, VDWT, as well as the KAMST. Parametric statistics was used only to compare the DCV scores between the two age groups.

Table 4.1

Results of Shapiro-Wilk test of normality for data obtained during the 4 evaluations from 20 participants

Test	**Ear/Score**	**Pre-training evaluation**				**Post-training evaluation**			
		1		**2**		**1**		**2**	
		W	***p***	***W***	***p***	***W***	***p***	***W***	***p***
Gap detection threshold on GIN	Right Ear	.86	.007	.74	.00	.85	.005	.87	.11
	Left Ear	.87	.01	.73	.00	.86	.008	.71	.001
Gap detection threshold on GDT	Right Ear	.91	.07	.92	.09	.88	.02	.83	.04
	Left Ear	.81	.001	.91	.05	.87	.01	.89	.17
Duration Pattern test	Right Ear	.75	.00	.76	.00	.73	.00	.73	.002
	Left Ear	.65	.00	.6	.00	.55	.00	.94	.57
Dichotic CV test	Right ear Single correct score	.96	.83	.98	.98	.91	.31	.95	.73
	Left ear Single correct score	.93	.48	.87	.11	.92	.39	.92	.36
	Double correct score	.91	.28	.95	.72	.96	.76	.94	.57
Speech perception in Noise test in Kannada	Right Ear	.96	.53	.88	.02	.98	.93	.94	.58
	Left Ear	.94	.24	.91	.06	.93	.13	.92	.38
Voicing discrimination word test	Right Ear	.92	.11	.83	.002	.78	.00	.89	.19
	Left Ear	.83	.002	.88	.02	.89	.02	.87	.09
Kannada Auditory Memory & Sequencing test	Auditory memory span	.78	.00	.87	.01	.85	.006	.8	.01
	Auditory sequencing span	.81	.001	.84	.004	.76	.00	.64	.00

To compare the performances of the two age groups on tests of auditory processing, voicing discrimination and auditory memory and sequencing, a Mann-Whitney test was carried out. The results of the test are shown in Table 4.2.

Table 4.2
Results of the Mann-Whitney test done to compare the two age groups on various tests of auditory processing, voicing discrimination as well as auditory memory and sequencing

Test	**Ear/Score**	**Pre-training evaluation**				**Post-training evaluation**			
		1		**2**		**1**		**2**	
		z	***p***	***z***	***p***	***z***	***p***	***z***	***p***
Gap detection threshold on GIN	Right Ear	0.79	.43	0.83	.41	0.17	.86	0.78	.43
	Left Ear	1.37	.17	0.98	.32	1.42	.15	1.94	.05
Gap detection threshold on GDT	Right Ear	1.59	.11	0.04	.97	1.0	.31	0.34	.73
	Left Ear	1.03	.3	2.16	.03	1.49	.13	0.0	1.0
Duration Pattern test	Right Ear	0.77	.44	1.0	.31	0.86	.39	1.33	.18
	Left Ear	1.62	.1	.40	.68	0.33	.74	1.3	.19
Dichotic CV test	Right SCS	0.92	.36	0.28	.78	0.4	.69	0.32	.74
	Left SCS	0.4	.69	2.31	.02	0.28	.78	0.64	.52
	Double correct score	0.52	.6	1.83	.06	0.2	0.84	0.53	.59
Speech perception in Noise test in Kannada	Right Ear	1.15	.25	1.48	.14	2.11	.03	1.87	.06
	Left Ear	1.55	.12	1.57	.12	1.84	.07	0.64	.52
Voicing	Right Ear	0.9	.36	0.16	.87	0.12	.9	1.33	.18

discrimination word test	Left Ear	0.21	.84	1.06	.29	0.36	.71	1.56	.12
Kannada Auditory Memory and Sequencing test	Auditory memory span	0.26	.79	0.04	.97	0.35	.73	0.71	.48
	Auditory sequencing span	0.17	.86	0.13	.89	0.7	.48	0.75	.45

Note. Right SCS = Right ear single correct score; Left SCS = Left ear single correct score.

As indicated in Table 4.2, a significant difference was not found between the performances across the two age groups for most of the tests that were administered. A significant difference was observed only for four of the 120 measures that were evaluated. Hence, the data of the two age groups were combined for further analyses as a significant difference did not occur for any specific test or a particular evaluation.

Further, as some of the older adults had hearing loss above 2000 Hz (26 ears), the raw data from these individuals were compared with those without hearing loss (14 ears). On observation of the raw data, it was found that the speech identification scores in quiet of those with hearing loss above 2 kHz did not differ significantly ($z = 0.6$, $p > .05$) from those without when tested using a Mann-Whitney test. This indicated that the presence of hearing loss above 2 kHz did not affect their speech identification performance. Hence, the data of all the participants were merged for further evaluation.

4.2 Comparison of performance on behavioural tests in pre-training evalauation-1 and pre-training evaluation-2

The mean, median and standard deviations of scores on the two pre-training evaluations (pre-training evaluation-1 & pre-training evaluation-2) on all the tests are given in Table 4.3. A Wilcoxon signed rank test was done to compare the performances on these two evaluations. This was done to check if the behavioural measures that were evaluated changed without intervention. It was observed that no significant difference existed between the performances in these two evaluations, as indicated in Table 4.4. Hence, only pre-training evaluation-1, the earlier amongst the two pre-training evaluations was used for comparison with the performances after temporal resolution training.

Table 4.3
Mean, Median and Standard deviations (SD) of various tests of auditory processing, voicing discrimination as well as auditory memory and sequencing

Test	**Ear/Score**	**Pre-training evaluation**					
		1			**2**		
		Mean	Median	SD	Mean	Median	SD
Gap detection threshold on GIN	Right Ear	9.35	9	2.91	8.45	8	3.35
	Left Ear	8.95	8	3.86	9.05	8	4.17
Gap detection threshold on GDT	Right Ear	4.95	5	1.28	4.75	5	1.07
	Left Ear	4.65	5	1.04	4.55	5	1.1
Duration Pattern test	Right Ear	26.85	28.5	4.14	26.95	28	3.76
	Left Ear	26.85	28.5	4.67	27.3	29	4.54
Dichotic CV test	Right SCS	21.2	22	4.52	22.1	22.5	3.46
	Left SCS	18.35	18	5.07	20.1	21.5	4.37
	Double correct score	10.85	11	5.97	13.3	14	6.79
SPIN-K	Right Ear	14.65	14.5	3.64	15.8	17.5	4.1

	Left Ear	15.95	17	3.78	15.5	16	3.3
Voicing discrimination word test	Right Ear	27.7	27.5	1.3	26.85	27.5	2.81
	Left Ear	28.45	29	1.67	27.45	28	2.0
Kannada Auditory Memory and Sequencing test	Auditory memory span	4.3	4	0.66	4.45	4	0.82
	Auditory sequencing span	4.1	4	0.72	4.35	4	0.81

Note. Right SCS = Right ear single correct score; Left SCS = Left ear single correct score.

Table 4.4

Comparison of performance between pre-training evaluation-1 and pre-training evaluation-2 on tests of auditory processing, voicing discrimination as well as auditory memory using Wilcoxon signed rank test

Test	**Ear/Score**	***z***	***p***
Gap detection thresholds on GIN	Right ear	1.28	.2
	Left ear	0.03	.98
Gap detection thresholds on GDT	Right ear	0.92	.36
	Left ear	0.7	.48
Duration Pattern test	Right Ear	0.29	.77
	Left Ear	1.1	.27
Dichotic CV test	Right SCS	0.83	.4
	Left SCS	1.14	.25
	Double correct score	1.54	.12
Speech perception in Noise test in Kannada	Right Ear	1.33	.18
	Left Ear	0.46	.65
Voicing	Right Ear	1.02	.3

discrimination word test	Left Ear	2.0	.05
Kannada Auditory Memory and Sequencing test	Auditory memory span	1.13	.26
	Auditory sequencing span	1.89	0.6

Note. Right SCS = Right ear single correct score; Left SCS = Left ear single correct score.

4.3 Effect of temporal resolution training on the auditory processing, voicing discrimination and auditory memory

The data obtained from the 20 participants on the three evaluations of the study (pre-training evaluation-1, post-training evaluation-1 & post-training evaluation-2) were compared to determine the effect of ATRT. This comparison of scores, before and after temporal resolution training (pre-evaluation 1, post-evaluations 1 & 2), was done separately for the seven behavioural tests that were administered (GIN, GDT, DPT, DCV, SPIN-K, VDWT-K, & KAMST,). Additionally, the effect of temporal resolution training on the objective measure (LLR) was also checked across the different evaluations (pre-training evaluation- 2, post-training evaluations- 1 & 2). The performance on the two post-training evaluations were compared to note if the changes in performances seen due to the temporal resolution training were maintained 4 weeks after the cessation of the training. This was evaluated in 50% of the total participants (10 participants) who were administered the temporal resolution training. Details of the results of each of the tests are described below.

The Wilcoxon signed rank test was used to compare pre-training evaluation-1 and post-training evaluation-1, while Friedman test was used to compare pre-training evaluation-1, and post-training evaluations- 1 and 2. The Wilcoxon test was used to compare pre-training evaluation-1 and post-training evaluation-1 since a larger number of participants partook in these evaluations (N = 20) and lesser in post-training evaluation-2 (N = 10). To avoid losing 10 data points, the Wilcoxon test was performed. Thus, the Friedman test used to compare pre-training evaluation-1 and post-training evaluations-1 and 2 analysed the data of only the 10 participants who were evaluated in all three evaluations.

4.3.1 Effect of temporal resolution training on the performance in Gap-In-Noise test.

Table 4.5 shows the mean, median, and standard deviation of the gap detection threshold obtained on GIN. The performance of the older adults was poorer compared to the values given by Aravindkumar et al. (2012) for young adults. It was observed that 17 individuals (85%) failed GIN prior to the temporal resolution training. The number of individuals who failed reduced to 5 (25%) following training.

Table 4.5

Mean, Median and Standard deviations (SD) for gap detection thresholds obtained using Gap-In-Noise test

	Right ear			**Left Ear**			**Left + Right**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation-1	9.35	9	2.91	8.95	8	3.86	9.15	8	3.38
Post-Training Evaluation- 1	5.85	6	1.14	6.05	6	1.85	5.95	6	1.52
Post-Training Evaluation- 2	6.2	6	1.4	7	8	1.33	6.6	6	1.39

Note: Pass criteria as per the norms of Aravindkumar et al. (2012) for GIN = 5.22 ± 2.22 ms; All values are in milliseconds; Left + Right = Scores of both ears combined

Prior to analysing the effect of training on gap detection thresholds, the presence of an ear effect was evaluated for each of the evaluations separately. Wilcoxon signed rank test showed no significant difference between the left and right ears for pre-training evaluation-1 ($z = -0.7$, $p > .05$), post-training evaluation-1 ($z = -0.83$, $p > .05$) and post-training evaluation-2 ($z = -2.0$, $p = .05$). Hence, the data of the two ears were combined for further analysis.

Scores depicted in Table 4.5 and Figure 4.1 indicates that the mean and median gap detection thresholds obtained on the two post-training evaluations improved following training. The SD also tended to decrease following training. The table and figure also indicate that the scores obtained by the older adults on the two post evaluations tend to overlap with each other. Further, it can be observed from the figure that these two post evaluations were equivalent or tended to be equivalent to the norms for young adults given by Aravindkumar et al. (2012). To confirm if the improvement seen after training was statistically significant, further analyses were carried out.

Findings immediately after cessation of training on GIN thresholds: To establish if the mean and median gap detection thresholds improved significantly soon after training, Wilcoxon signed rank test was done. It was observed that there existed a significant improvement in post-training evaluation-1 compared to pre-training evaluation-1 ($z = -5.12$, $p < .001$), as can be seen in Figure 4.1.

Findings one month post cessation of training on GIN thresholds: The effect of temporal resolution training, 4 weeks after its cessation, was determined by comparing the performance on post-training evaluation-2 with pre-training evaluation-1 as well as with post-training evaluation-1. A Friedman test revealed a significant overall difference between the performances on these three evaluations ($\chi^2(2) = 19.81$, $p < .001$). To confirm if such a difference existed between pairs of evaluations, Wilcoxon signed rank test done. A significant higher performance was seen in post-training evaluation-1 compared to pre-training evaluation-1 ($z = 3.34$, $p < .01$). However, post-training evaluation-1 and 2 were not significantly different ($z = 1.46$, $p > .05$).

Figure 4.1 a

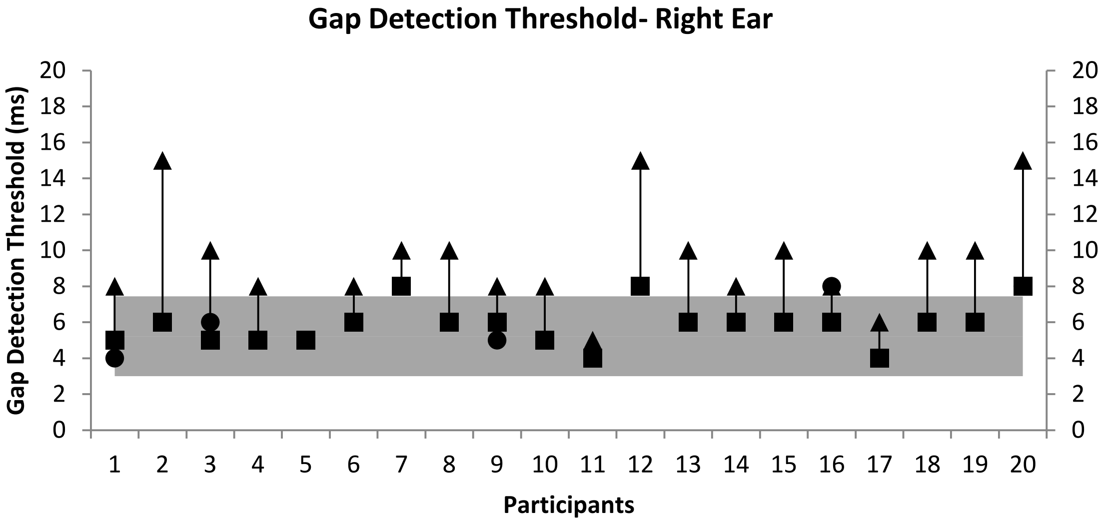


Figure 4.1 b

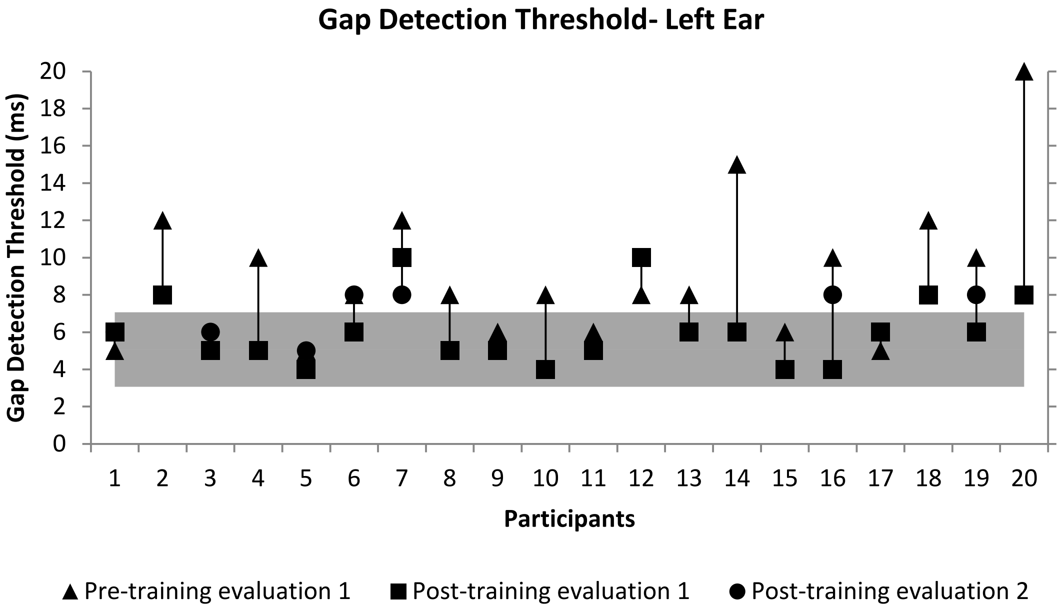


Figure 4.1. Individual gap detection thresholds obtained for right ear (a) and left ear (a) on GIN across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.2 Effect of temporal resolution training on the performance in Gap Detection Test.

The mean, median, and standard deviation of gap detection thresholds obtained for the right and left ears using the Gap Detection Test are shown in Table 4.6. From the table it is evident that the mean gap detection thresholds of the older adults were poorer compared to that of young adults reported by Shivaprakash (2003). The number of older individuals who failed GDT before and after administration of temporal resolution training reduced from 16 (80%) to 3 (15%).

Table 4.6
Mean, median and Standard deviations (SD) of gap detection thresholds obtained on the Gap Detection Test

	Right ear			**Left Ear**			**Left + Right**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation-1	4.95	5	1.28	4.65	5	1.04	4.8	5	1.16
Post-Training Evaluation-1	2.7	3	1.08	2.85	3	0.87	2.77	3	0.97
Post-Training Evaluation-2	3.5	3	1.35	3.4	3	0.84	3.45	3	1.1

Note: Pass criteria for GDT = 3.3 ± 1.32 ms as per norms of Shivaprakash (2003); Left + Right = Scores of both ears combined

To check if the change in gap detection threshold required to be tested independently for each ear or could be combined, the performance of the two ears in each of the evaluations was compared. The results of a Wilcoxon signed rank test indicated that a significant difference was not present between the gap detection thresholds of the two ears for pre-training evaluation-1 ($z = -1.43$, $p > .05$), post-training evaluation-1 ($z = -$

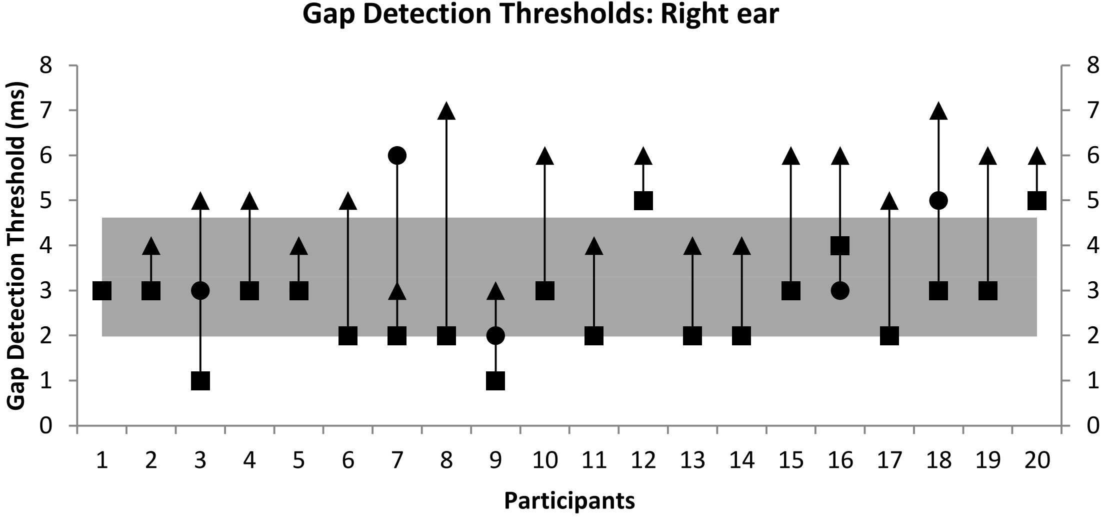
0.4, $p > .05$), and post-training evaluation-2 ($z = -0.35$, $p > .05$). Since no ear difference was present, for subsequent analyses the data obtained from the two ears were combined.

From Table 4.6, it can be observed that the mean and median gap detection thresholds showed improvement after temporal resolution training. This improvement was present for each of the ears independently and when the data for the two ears were combined. In addition, from Figure 4.2 it is evident that the gap detection thresholds obtained after training were similar / better than that reported for young adults by Shivaprakash (2003), which is provided in the shaded area of the graph. To evaluate if the improvement was significant, further comparisons were made.

Findings immediately after cessation of training on thresholds of GDT: A Wilcoxon signed rank test was done to compare pre-training evaluation-1 and post-training evaluation-1 scores to determine the effect of temporal resolution training on gap detection thresholds soon after the cessation of training. The performance was found to be significantly better in the post-training evaluation-1 compared to the pre-training evaluation-1 ($z = -5.3$, $p < .001$).

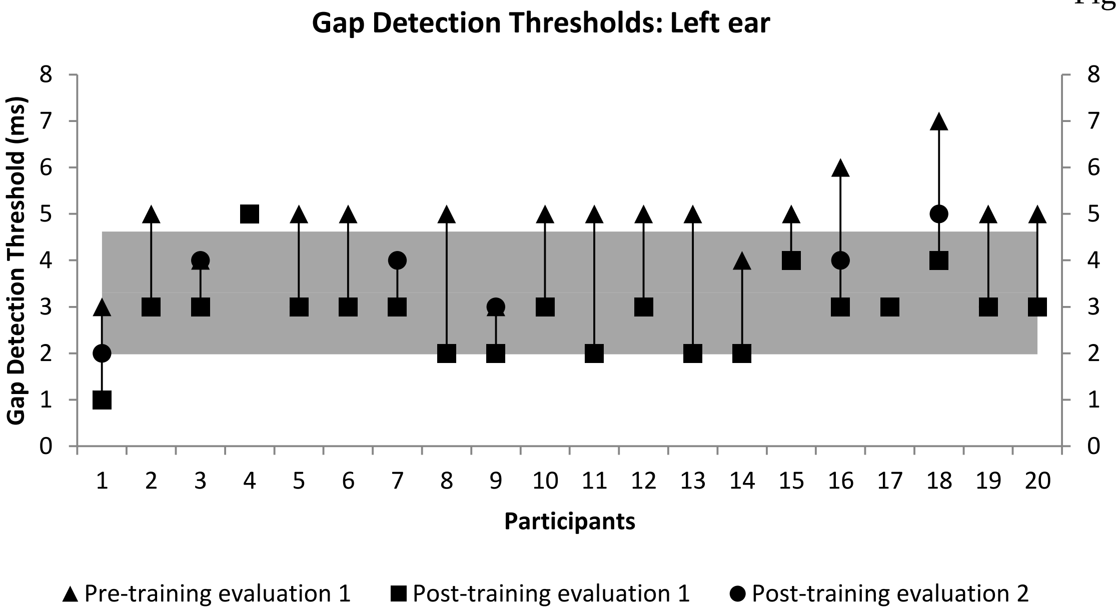
Findings one month post cessation of training on thresholds of GDT: The performance of the participants 4 weeks following the cessation of temporal resolution training was obtained to determine the maintenance of the learnt task. The gap detection threshold obtained in post-training evaluation-2 was compared with pre-training evaluation-1 and post-training evaluation-1. A Friedman test comparing across these three evaluations revealed a significant overall difference between the performances across these evaluations ($\chi^2(2) = 26.25$, $p < .001$). Further, a Wilcoxon signed rank test showed significant better thresholds in post-training evaluation-2 compared to pre-training evaluation-1 ($z = -2.79$, $p < .01$). Similarly, a significant difference was found between the two post-training evaluations ($z = -2.65$, $p < .01$).

Figure 4.2 a



Gap Detection Thresholds: Right ear

Figure 4.2 b



Gap Detection Thresholds: Left ear

Figure 4.2. Individual gap detection thresholds obtained on GDT for right ear (a) and left ear (b) across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.3 Effect of temporal resolution training on the performance in Duration Pattern Test (DPT).

The impact of temporal resolution training on the mean, median and standard deviation of the Duration Pattern Test scores is provided in Table 4.7. The older adults were found to obtain poorer scores compared to the young adults studied by Gauri (2003). The number of individuals who failed DPT, based on the norms of young adults given by Gauri, was 11 (55%) before they were administered the temporal resolution training. This reduced marginally to 9 (45%) after the administration of training. Further, from the scores provided in the table, it can be observed that temporal resolution training resulted in a marginal improvement in the performance in the older adults. The marginal change in performance is also indicated in Figure 4.3 where the scores for each of the evaluations tend to overlap or show minimal change in many participants. The data in Figure 4.3 are provided using percentage in order to compare them with the norms given by Gauri (2003) that are in percentage. However, raw scores were used for statistical analysis of the performances on the three evaluations.

Table 4.7
Mean, Median and Standard deviations (SD) for scores obtained on the Duration Pattern test

	Right ear			**Left Ear**			**Left + Right**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation- 1	26.85	28.5	4.14	26.85	28.5	4.67	26.85	28.5	4.36
Post-Training Evaluation- 1	28.05	29	2.76	28.15	29	3.33	28.1	29	3.01
Post-Training	27.7	29	2.91	27.4	28	1.9	27.55	28	2.39

Evaluation- 2									

Note. Maximum possible score = 30; Left + Right = Scores of both ears combined.

Initially, the presence of an ear difference was checked to determine whether the scores of the two ears could be combined or not. No significant difference was found between the performances of the two ears during pre-training evaluation-1 ($z = -0.39$, $p > .05$), post-training evaluation-1 ($z = -0.35$, $p > .05$) and post-training evaluation-2 ($z = -0.52$, $p > .05$). Hence, the data of the two ears were combined for further comparisons.

To establish if the change in performance with training was statistically significant, the scores obtained in pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2 were compared. Pre-training evaluation-1 and post-training evaluation-1 were compared separately from the comparisons done with post-training evaluation-2. This was done to avoid losing data points since not all participants partook in post-evaluation-2.

Findings immediately after cessation of training on scores in DPT: To assess the effect of temporal resolution training on scores of the Duration Pattern Test immediately after cessation of training a Wilcoxon signed rank test was performed using the data of all 20 participants. A significant difference in scores obtained on pre-training evaluation-1 and post-training evaluation-1 was found ($z = -3.39$, $p < .01$).

Findings one month post cessation of training on scores in DPT: The maintenance of temporal resolution training on scores of duration pattern test four weeks after training was evaluated using a Friedman test. The Friedman test, comparing the performances of the 10 participants who were evaluated on all three evaluations showed no significant difference ($\chi^2(2) = 4.53$, $p > .05$). Hence, further comparisons were not carried out.

Figure 4.3 a

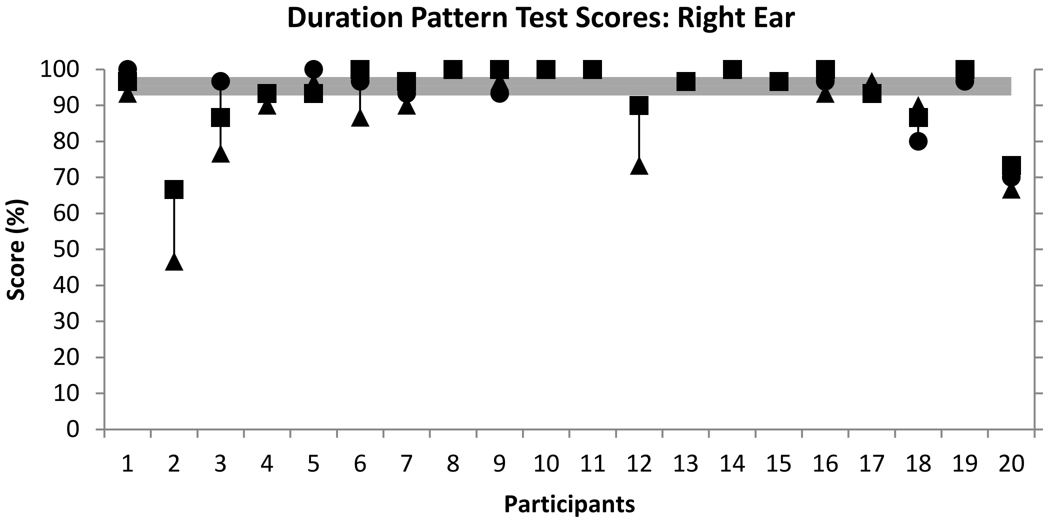


Figure 4.3 b

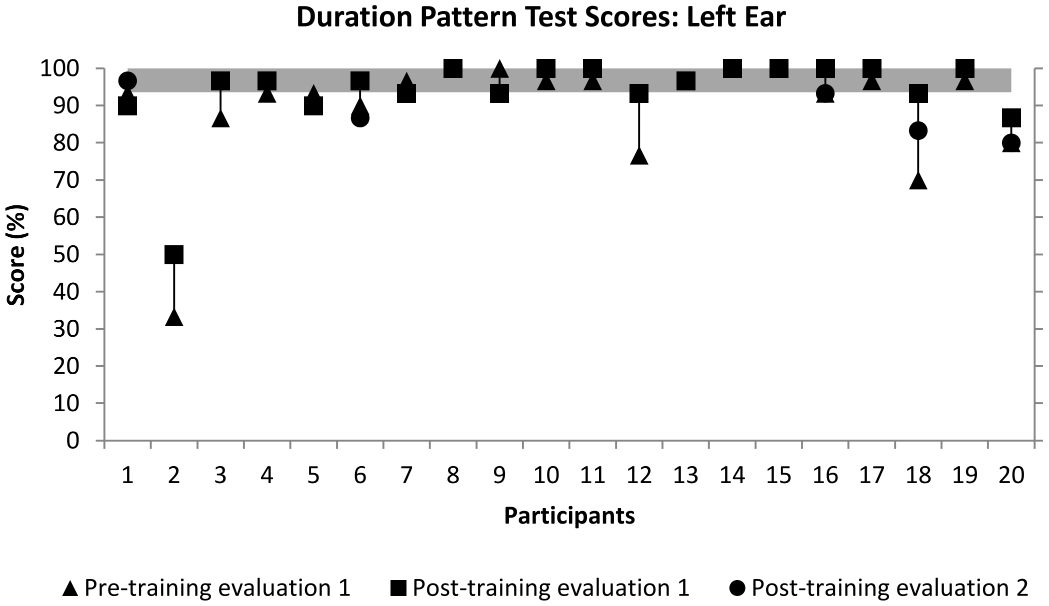


Figure 4.3. Individual scores obtained on Duration Pattern Test for right ear (a) and left ear (b) across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

Note: Percentage scores have been used in the figure as the norms of Gauri (2003) for young adults are provided in percentage.

4.3.4 Effect of temporal resolution training on the performance in Dichotic CV Test.

Table 4.8 provides the mean, median, and standard deviation of the single correct and double correct scores obtained before and after the administration of temporal resolution training. Fifteen (75%) older adults were found to fail the dichotic CV test prior to the training, when their scores were compared with the norms of young adults provided by Prachi (2000). Following temporal resolution training, the number of failures dropped to 8 (40%). The improvement in the performance seen in post-training evaluation-1 is also evident in Figure 4.4. From Table 4.8 and Figure 4.4 it is evident that the performance of the older individuals on the dichotic CV test was poorer than that reported by Prachi (2000) in young adults.

Table 4.8
Mean, Median and Standard deviations (SD) for scores obtained on Dichotic CV test

	Right ear single correct			**Left Ear single correct**			**Double correct**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation- 1	21.2	22	4.52	18.35	18	5.07	10.85	11	5.97
Post-Training Evaluation- 1	24.25	24	3.55	21.25	21	3.52	16.3	17.5	5.49
Post-Training Evaluation- 2	23.5	23.5	3.06	21.1	20.5	4.17	15.1	14	4.58

Note. Maximum possible score = 30

As the scores on dichotic CV test across the evaluations were normally distributed, a repeated measure ANOVA was performed to compare the scores across the evaluations before and after training. Additionally, analysis was done to check if the ear /

scoring procedure (right ear single correct, left ear single correct & double correct) influenced the results.

Findings immediately after cessation of training on scores in DCV test: To study the effect of temporal resolution training on dichotic CV test scores immediately after its cessation a repeated measure ANOVA was done with evaluations (pre-training evaluation-1, & post-training evaluation-1) as independent variable and scores (right ear single correct, left ear single correct & double correct) as dependent variables. Significant effects of evaluation ($F(1, 19) = 15.93$, $p < .01$) and score ($F(2, 38) = 61.21$, $p < .001$) were found. The interaction between the two factors was also noted to be significant ($F(2, 38) = 3.62$, $p < .05$). A pair-wise comparison after Bonferroni correction showed a significant improvement in scores from pre-training evaluation-1 to post-training evaluation-1 ($p < .01$). The pair-wise comparison also revealed that the single correct right ear scores were significantly better than left ear scores ($p < .05$). Further, the double correct scores were observed to be significantly poorer than that of the right ear single correct scores ($p < .001$) and left ear single correct scores ($p < .001$).

Findings one month post cessation of training on scores in DCV test: To evaluate the effect of temporal resolution training on the dichotic CV test scores four weeks after the termination of training, a repeated measure ANOVA was performed once again. This was done with evaluations (pre-training evaluation-1, post-training evaluation-1 & post-training evaluation-2) as independent variable and the scores (right ear single correct, left ear single correct & double correct) as dependent variables. Significant effects of evaluation ($F(2, 18) = 6.2$, $p < .01$) and score ($F(2, 18) = 25.54$, $p < .001$) were observed. However, the interaction between the two factors was not significant ($F(4, 36) = 1.68$, $p >$

.05). The post-hoc pair-wise comparison with Bonferroni correction showed that a significant difference existed between pre-training evaluation-1 and post-training evaluation-1. However, a significant difference was not found between the two post-training evaluations.

Figure 4.4 a

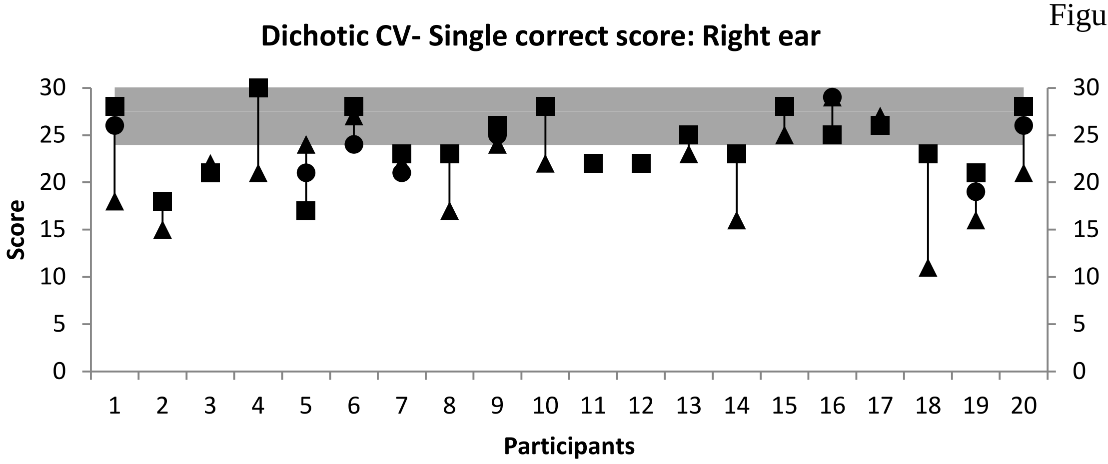


Figure 4.4 b

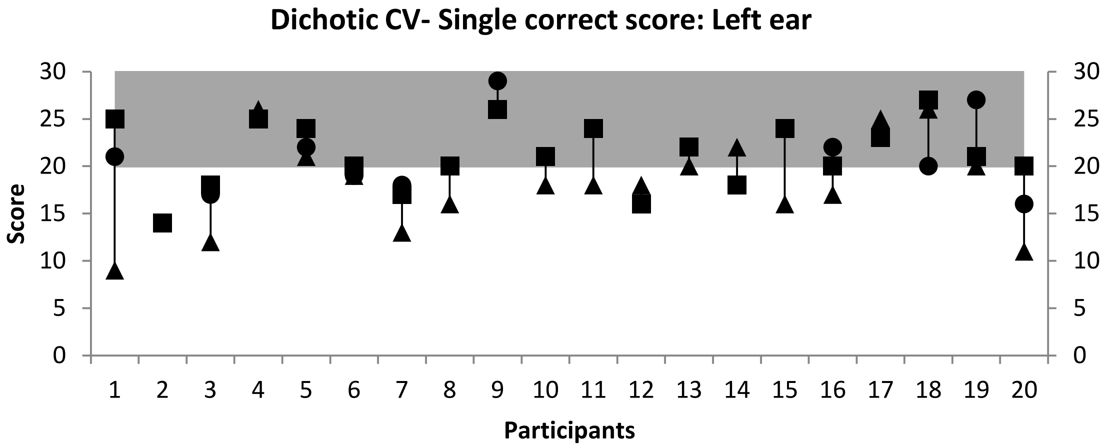


Figure 4.4 c

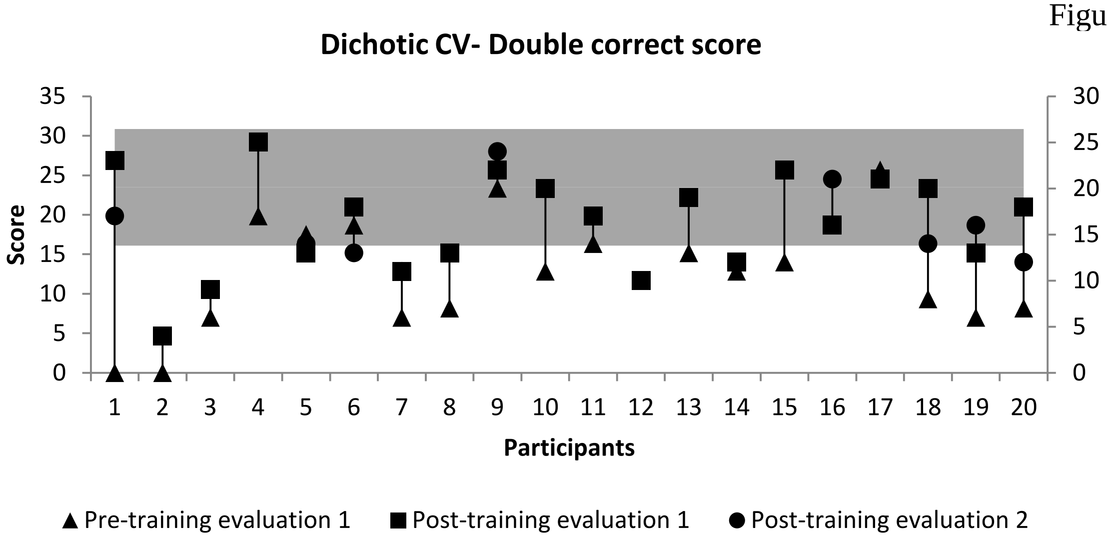


Figure 4.4. Individual Single correct score of the right ear (a), Single correct score of the left ear (b) and Double correct score (c) on the Dichotic CV test across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.5 Effect of temporal resolution training on the performance in Speech-Perception-in-Noise test in Kannada.

From the mean, median, and standard deviation of SPIN-K scores shown in Table 4.9, an improvement in scores can be seen following training. This is also evident in **Error! Reference source not found.**. With this improvement the number of individuals who failed the test subsequent to training went down from 13 (65%) to 4 (20%). The pass / fail criteria were based on the criteria given by Kalikow et al. (1977).

Table 4.9
Mean, Median and Standard deviations (SD) of scores obtained on Speech Perception in Noise test in Kannada

	Right ear			**Left ear**			**Left + Right**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation- 1	14.65	14.5	3.64	15.95	17	3.78	15.3	15.5	3.72
Post-Training Evaluation- 1	17.85	18	2.91	17.65	18	2.32	17.75	18	2.6
Post-Training Evaluation- 2	17.2	18	3.29	17.5	18	2.55	17.35	17.5	2.87

Note. Maximum possible score = 25; Left + Right = Scores of both ears combined.

Prior to the comparison of the performance on the pre-training and post-training evaluations, the scores of the two ears on each of these evaluations were compared using a Wilcoxon signed rank test. No significant difference between the performances of the two ears was observed for pre-training evaluation-1 ($z = -1.172$, $p > .05$), post-training evaluation-1 ($z = -0.08$, $p > .05$) and post-training evaluation-2 ($z = -0.3$, $p > .05$). Since no significant difference occurred between the two ears, subsequent analyses were done with the SPIN-K data of the two ears combined.

Findings immediately after cessation of training on scores in SPIN-K: The change in performance on SPIN-K soon after the ending of temporal resolution training was obtained by comparing the performance on pre-training evaluation-1 and post-training evaluation-1. A Wilcoxon signed rank test indicated the presence of a significant improvement in post-training evaluation-1 (z = -4.34, p < .001).

Findings one month post cessation of training on scores in SPIN-K: The maintenance of the improvement following training was calculated by comparing post-training evaluation-2 with post-training evaluation-1 as well as with pre-training evaluation-1. A Friedman test, comparing the performances, revealed a significant overall difference ($\chi^2(2) = 12.91$, p < .01) across the three evaluations. Further Wilcoxon test showed a significant improvement in SPIN-K scores in post-training evaluation-2 over pre-training evaluation-1 (z = -2.83; p < .01). However, a significant difference was not found between the scores in post-training evaluations-1 and 2 (z = -0.77; p > .05).

Figure 4.5 a

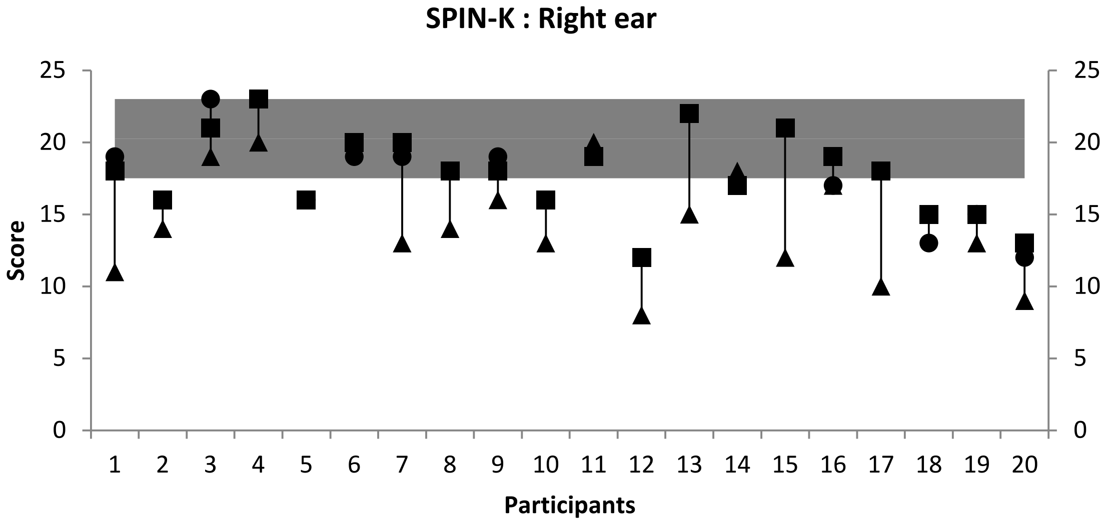


Figure 4.5 b

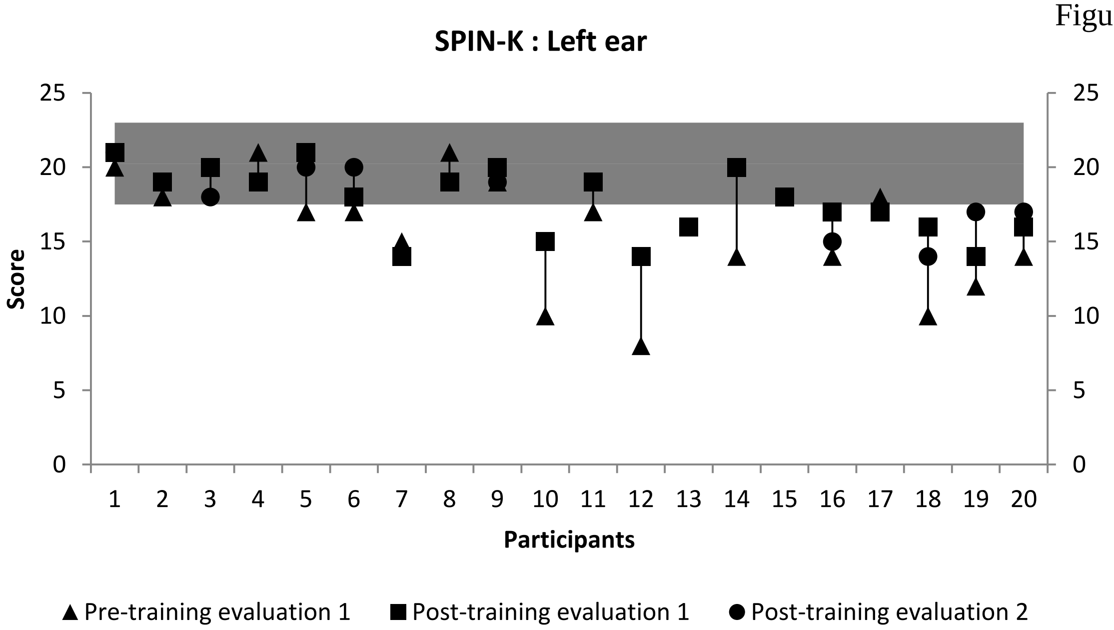


Figure 4.5. Individual scores obtained on Speech Perception in Noise test in Kannada (SPIN-K) for right ear (a) and left ear (b) across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.6 Effect of temporal resolution training on voicing discrimination.

From Table 4.10 that provides the mean, median and standard deviation of the Voicing discrimination word test in Kannada scores, it is evident that temporal resolution training did not bring about much change. This is also indicated in the Figure 4.6 where it can be seen that the scores across the three evaluations overlap and do not show change in the majority of the participants. To examine if this change was significant, further analyses were done.

Table 4.10
Mean, Median and Standard deviations (SD) of scores obtained on the Voicing discrimination word test

	Right ear			**Left ear**			**Left + Right**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation-1	27.7	27.5	1.3	28.45	29	1.67	28.07	28.5	1.52
Post-Training Evaluation-1	28.35	29	1.81	28.35	29	1.56	28.35	29	1.67
Post-Training Evaluation-2	28.2	28	1.03	28.2	28.5	1.4	28.2	28	1.2

Note. Maximum possible score = 30; Left + Right = Scores of both ears combined.

As done with the earlier tests, before analysing the effect of training on test scores, a Wilcoxon signed rank test was performed to establish whether there existed an ear difference. A significant difference was not found between the performances of the two ears during the pre-training evaluation-1 ($z = -1.67$, $p > .05$), post-training evaluation-1 ($z = -0.34$, $p > .05$) and post-training evaluation-2 ($z = 0.0$, $p > .05$). The absence of an ear difference permitted pooling together the data of the two ears for the further analysis.

Findings immediately after cessation of training on Voicing discrimination: Changes in the scores of the ‘Voicing discrimination word test in Kannada’ at the end of the temporal resolution training was calculated by comparing the scores of pre-training evaluation-1 with post-training evaluation-1. The findings of a Wilcoxon signed rank test highlighted that pre-training evaluation-1 and post-training evaluation-1 did not differ significantly ($z = -0.87$, $p > .05$).

Findings one month post cessation of training on Voicing discrimination: A comparison of post-training evaluation-2 with the performance on pre-training evaluation-1 and post-training evaluation-1 shed light on the voicing discrimination performance one month after the end of training. A Friedman test showed no significant difference in voicing discrimination across the three evaluations ($\chi^2(2) = 0.42$, $p > .05$).

Figure 4.6 a

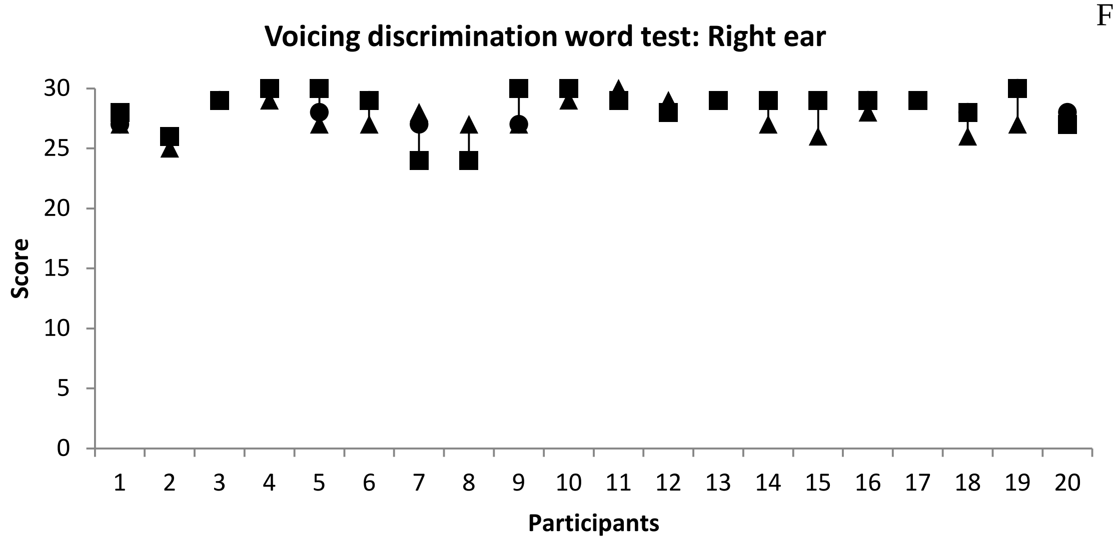


Figure 4.6 b

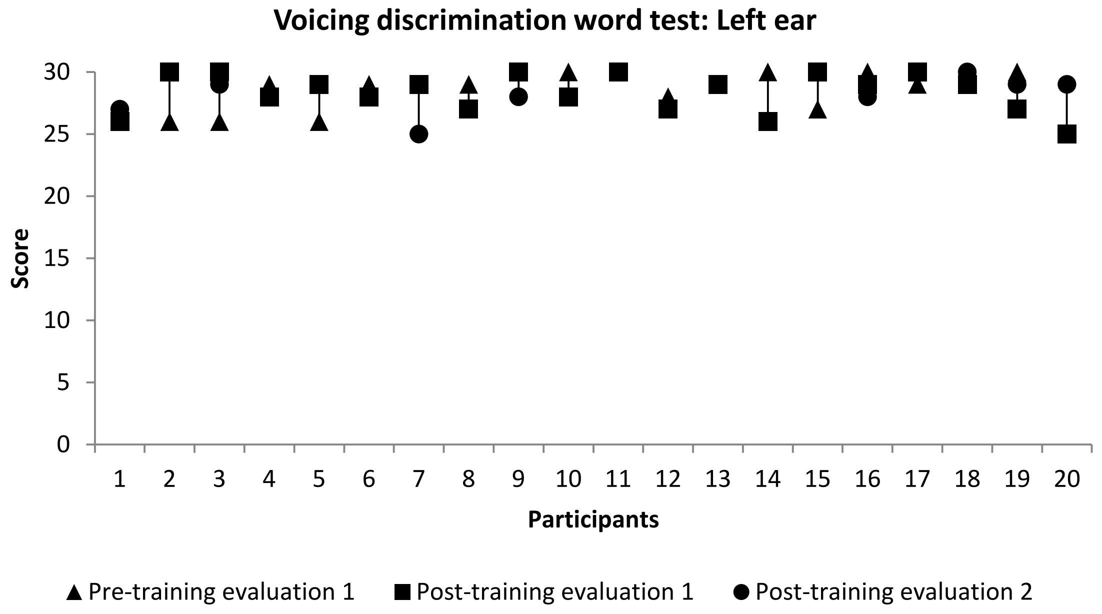


Figure 4.6. Individual scores obtained on the Voicing discrimination word test in Kannada for right ear (a) and left ear (b) across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.7 Effect of temporal resolution training on the performance in Kannada Auditory Memory and Sequencing Test.

The mean, median, as well as standard deviation of auditory memory span and sequencing span tested binaurally in the three evaluations are shown in Table 4.11. From the table it can be see that the mean auditory memory and sequencing span changed only marginally with temporal resolution training. Although the changes seen in the auditory memory span was marginal, the percentage of individuals who had reduced memory span when compared with the norms of Vaidyanath and Yathiraj (2014a) decreased from 60% to 5% after training. Whereas, the reduction in the percentage of individuals with reduced sequencing span was only marginal 20% to 10% (Figure 4.7). However, it can be observed from the overlapping points in Figure 4.7 that some of the participants do not show any change in their auditory memory and sequencing span.

Table 4.11
Mean, Median and Standard deviations (SD) of scores obtained on the Kannada Auditory Memory and Sequencing Test

	Auditory Memory span			**Auditory sequencing span**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**
Pre-Training Evaluation-1	4.3	4	0.66	4.1	4	0.72
Post-Training Evaluation-1	4.65	5	0.74	4.4	4.5	0.68
Post-Training Evaluation-2	4.7	5	0.67	4.4	4	0.51

Note. Maximum possible span score = 8

Findings immediately after cessation of training on KAMST: Immediately after the cessation of temporal resolution training, the impact on auditory memory and sequencing span was calculated. This was done by comparing the performance on pre-training evaluation-1 and post-training evaluation-1 using a Wilcoxon signed rank test. It was observed that a significant improvement in auditory memory span occurred ($z = -2.33$, $p < .05$) but no such improvement was seen for the auditory sequencing span ($z = -1.7$, $p > .05$).

Findings one month post cessation of training on KAMST: The maintenance of auditory memory performance 4 weeks post cessation of temporal resolution training was evaluated using a Friedman test. The post-training evaluation-2 scores were compared with the performances in pre-training evaluation-1 and post-training evaluation-1. A significant overall difference in performance was present across the three evaluations for auditory memory span ($\chi^2(2) = 7.0$, $p < .05$) but not for auditory sequencing span ($\chi^2(2) = 2.0$, $p > .05$). Wilcoxon signed rank test demonstrated a significant difference in auditory memory span between post-training evaluation-2 and pre-training evaluation-1($z = -2.0$, $p < .05$) but not between post-training evaluation-1 and post-training evaluation-2 ($z = -0.58$, $p > .05$).

Figure 4.7 a

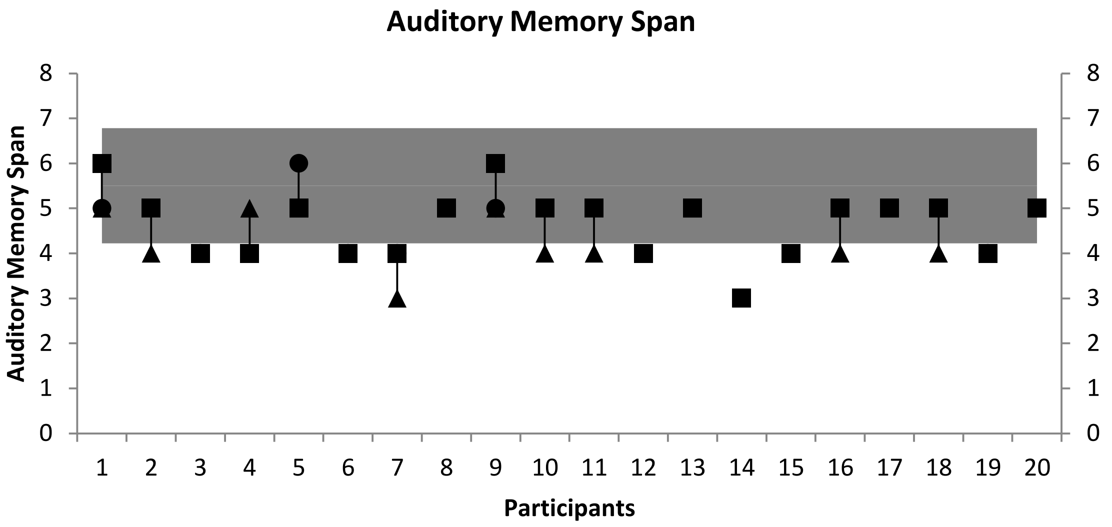


Figure 4.7 b

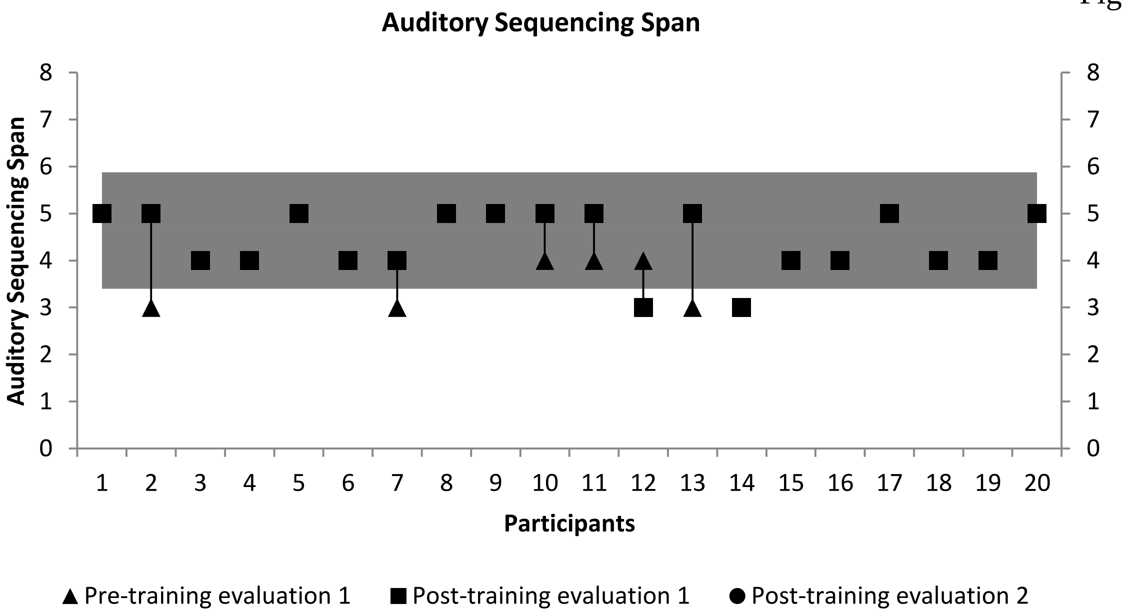


Figure 4.7. Individual auditory memory span (a) and auditory sequencing span (b) obtained on the Kannada Auditory Memory and Sequencing Test across pre-training evaluation-1, post-training evaluation-1 and post-training evaluation-2.

4.3.8 Effect of temporal resolution training on the phoneme error pattern in the presence of noise.

The phoneme errors across the three evaluations are shown in Table 4.12. These errors were obtained from the responses of the Speech-perception-in-noise test in Kannada. As a significant difference in the performance of the two ears was not found for the scores of SPIN-K using a Wilcoxon signed rank test as mentioned earlier, the data from the two ears were combined for the phoneme error analysis. The mean, median, and standard deviations of the errors in terms of place, manner, voicing, in isolation and in combination are given in the Table 4.12. As the standard deviations were higher than the mean for most of features that were considered (Table 4.12), inferential statistics was not possible. Hence, the total number of errors was calculated (Table 4.13) for further statistical analysis.

Table 4.12
Mean, Median and Standard deviations (SD) of the phoneme errors obtained from responses of Speech Perception in Noise test in Kannada

Error type	**Pre-training evaluation-1**			**Post-training evaluations-1**			**Post-training evaluations-2**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Place	0.45	0	0.6	0.75	1	0.97	0.5	0	0.97
Manner	1.25	1	0.85	1.5	1	1.05	1.2	1	1.03
Voicing	0.8	1	0.62	0.79	1	0.53	0.56	1	0.53
Place+Manner	2.25	2	1.07	2.25	2.5	1.37	1.9	1.5	1.52
Place+Voicing	0.4	0	0.5	0.53	0	0.7	0.6	0	0.84
Manner+Voicing	1.4	1	0.68	1.35	1	0.59	0.5	0	0.71
Place+Manner+Voicing	0.85	1	0.67	0.89	1	0.57	0.7	1	0.67

It can be observed from Table 4.13 that the total number of errors reduced after training. Further statistical analyses were carried out to check if this was significant.

Table 4.13
Number of phoneme errors of each type and total number of errors

Error type	**Pre-training evaluation-1 (N = 20)**	**Post-training evaluation-1 (N = 20)**	**Post-training evaluation-2 (N = 10)**
Place	9	15	5
Manner	25	30	12
Voicing	16	15	5
Place+Manner	45	45	19
Place+Voicing	8	10	6
Manner+Voicing	28	27	5
Place+Manner+Voicing	17	17	7
No-response	151	65	42
Phoneme addition	33	32	13
Phoneme deletion	17	16	9
Total	**349**	**272**	**123**

Findings immediately after cessation of training on phoneme errors: The effect of temporal resolution training on the total phoneme errors was evaluated by comparing the total number of errors in pre-training evaluation-1 with post-training evaluation-1. The Wilcoxon signed rank test showed a significant difference between the two evaluations ($z = -3.67$, $p < .001$).

Findings one month post cessation of training on phoneme errors: The phoneme errors 4 weeks post the cessation of training was calculated by comparing the performance on post-training evaluation-2 with pre-training evaluation-1 and post-training evaluation-1. The Friedman test revealed a significant difference ($\chi^2(2) = 11.84$, $p < .01$). Further, Wilcoxon test showed significant difference between pre-training evaluation-1 and post-training evaluation-2 ($p < .05$) as well as post-training evaluation-1 and post-training evaluation-2 ($p > .05$).

4.3.9 Effect of temporal resolution training on Speech evoked cortical responses.

The speech evoked cortical responses that were obtained in the current study included the Mismatch Negativity (MMN) and the Late Latency Response (LLR). As the MMN responses were absent in the majority of the older adults, the responses were evaluated for the N1 and P2 latency and amplitude of the LLR.

4.3.9.1 Effect of temporal resolution training on the latency of LLR.

The responses obtained for the two stimuli /ṭa/ and /ḍa/ at the three response-acquisition sites (F4, F3, & Cz) are given in the Table 4.14 and Table 4.15. The LLR were compared across the three evaluations in which they were acquired (pre-training evaluation-2, post-training evaluation-1, & post-training evaluation-2). It can be observed from the two tables that the N1 and P2 responses showed a decrease in mean latency across the three evaluations. This decrease in the latency of LLR was observed for both the stimuli used and at all the response acquisition sites. To discern if the data followed a normal distribution, a Shapiro-Wilk test was initially performed. As the data showed normal distribution, parametric statistics were used for further comparisons.

Table 4.14

Mean and standard deviation of latency of N1 and P2 peaks in milliseconds (ms) for /ṭa/ stimuli at F4, F3 and Cz

Site	Response / Evaluation	N1 (ms)			P2 (ms)		
		Mean	**Median**	**SD**	**Mean**	**Median**	**SD**
F4	Pre-Training Evaluation- 2	116.35	115.5	10.56	201.3	200.5	14.67
	Post-Training Evaluation- 1	113.25	113	11.27	195.15	194.5	10.49
	Post-Training Evaluation- 2	109.6	109.5	11.01	190.5	189	14.66
F3	Pre-Training Evaluation- 2	114.15	115	10.01	199.65	199	15.64
	Post-Training Evaluation- 1	110.4	110.5	10.24	193.45	192.5	8.85
	Post-Training Evaluation- 2	108.4	109.5	8.34	191.6	192.5	12.88
Cz	Pre-Training Evaluation- 2	113.3	112	9.42	197.65	196.5	18.38
	Post-Training Evaluation- 1	111.85	112.5	9.62	193.25	193	10.21
	Post-Training Evaluation- 2	107.4	107	9.17	190.2	191	13.77

Table 4.15
Mean and standard deviation of latency of N1 and P2 peaks in milliseconds (ms) for /ḍa/ stimuli at F4, F3 and Cz

Site	Response / Evaluation	N1 (ms)			P2 (ms)		
		Mean	**Median**	**SD**	**Mean**	**Median**	**SD**
F4	Pre-Training Evaluation- 2	115.1	114	10.37	194.35	192	16.64
	Post-Training Evaluation- 1	111.15	110	10.61	195.8	198	13.31
	Post-Training Evaluation- 2	107.6	106.5	12.65	189.6	198.5	21.35
F3	Pre-Training Evaluation- 2	113.45	110.5	10.77	194.85	193	18.92
	Post-Training Evaluation- 1	109.3	109	9.91	194.6	199	13.59
	Post-Training Evaluation- 2	106.1	107	11.55	187.7	194	19.01
Cz	Pre-Training Evaluation- 2	114.5	112.5	11.44	193.85	194.5	15.59
	Post-Training Evaluation- 1	109.15	108	9.53	194.35	199	13.19
	Post-Training Evaluation- 2	105.9	105.5	12.37	190.00	199.5	19.0

Findings immediately after cessation of training on LLR latency: A repeated measure ANOVA was performed to evaluate the effect of temporal resolution training on latency of speech evoked cortical responses immediately after its cessation. This was done with stimuli (/ṭa/ & /ḍa/), response acquisition site (F4, F3 and Cz), and evaluations (pre-training evaluation-2 and post-training evaluation-1) as independent variables and the response (N1 & P2) as a dependent variable. It was observed that the main effect of stimuli was not significant ($F(1, 19) = 1.02, p > .05$). The response acquisition site ($F(1.42, 26.95) = 5.38, p < .01$), the response considered ($F(1, 19) = 1788.85, p < .001$) and the evaluation ($F(1, 19) = 5.1, p < .05$) all showed significant effects. A pair-wise comparison with Bonferroni correction showed that the latency at F4 was similar to that at Cz ($p > .05$) but significantly different from that at F3 ($p < .05$) when evaluations and stimuli were combined. The pair-wise comparison also showed a significant difference in the mean latencies before and after temporal resolution training ($p < .05$) when the responses and evaluations were combined. However, none of the interactions were found to be significant. Further, pair-wise comparisons were done to check the effect of training on responses acquired for each response acquisition site. The paired sample t-test showed significant difference between the latency of N1 across the evaluations at F4 ($t = 2.31$, df = 39, $p < 0.05$), F3 ($t = 2.73$, df = 39, $p < 0.01$) and at Cz ($t = 2.31$, df = 39, $p < 0.05$). On the other hand no significant difference was observed for P2 latency at F4 ($t = 0.95$, df = 39, $p > 0.05$), F3 ($t = 1.18$, df = 39, $p > 0.05$) and Cz ($t = 0.76$, df = 39, $p > 0.05$). Thus, the results indicate that temporal resolution training had a significant effect only on the N1 latency of LLR.

Findings one month post cessation of training on LLR latency: The effect of temporal resolution training on the latencies of N1 and P2 one month after providing training was obtained by comparing the two post-training evaluations. A repeated measure ANOVA revealed no significant effect of stimuli ($F(1, 9) = 0.53, p > .05$), response acquisition site ($F(2,18) = 1.8, p > .05$) and the evaluations ($F(1,9) = 1.41, p >$

.05). However, a significant difference was found between the latencies of the peaks considered (*F*(1,9) = 628.12, *p* < .001) with stimuli and evaluation combined.

Figure 4.8 a

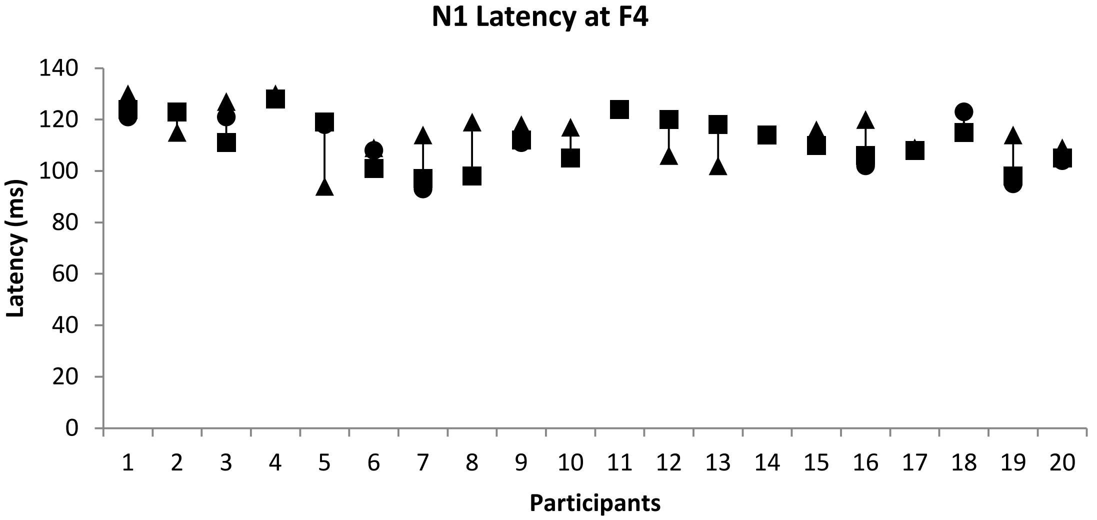


Figure 4.8 b

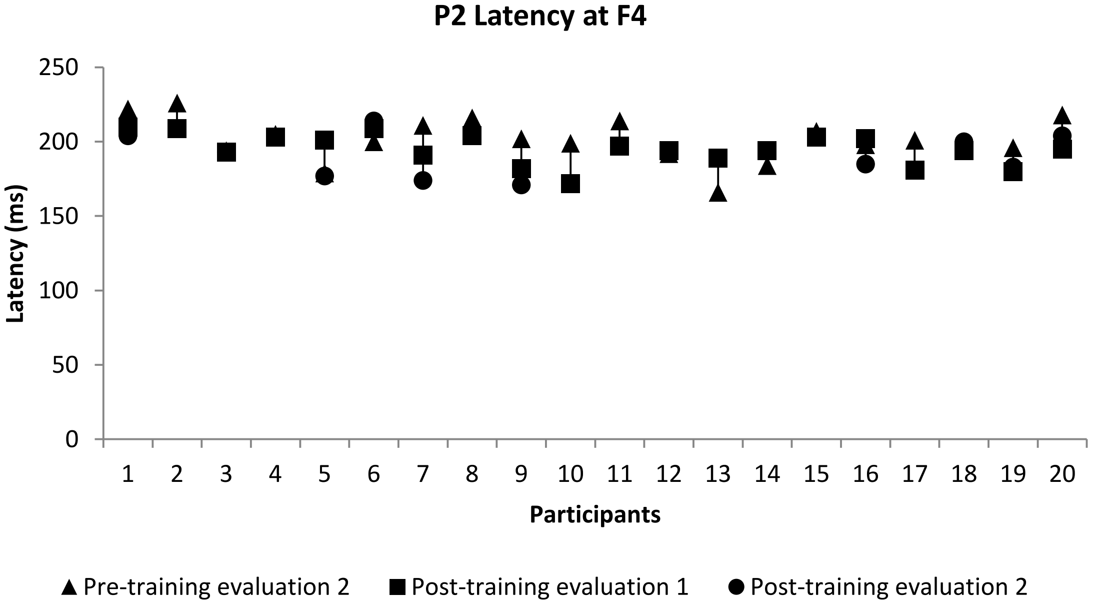


Figure 4.8 . Individual latencies of (a) N1 and (b) P2 for /ṭa/ at F4 for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.9 a

Figure 4.9 b

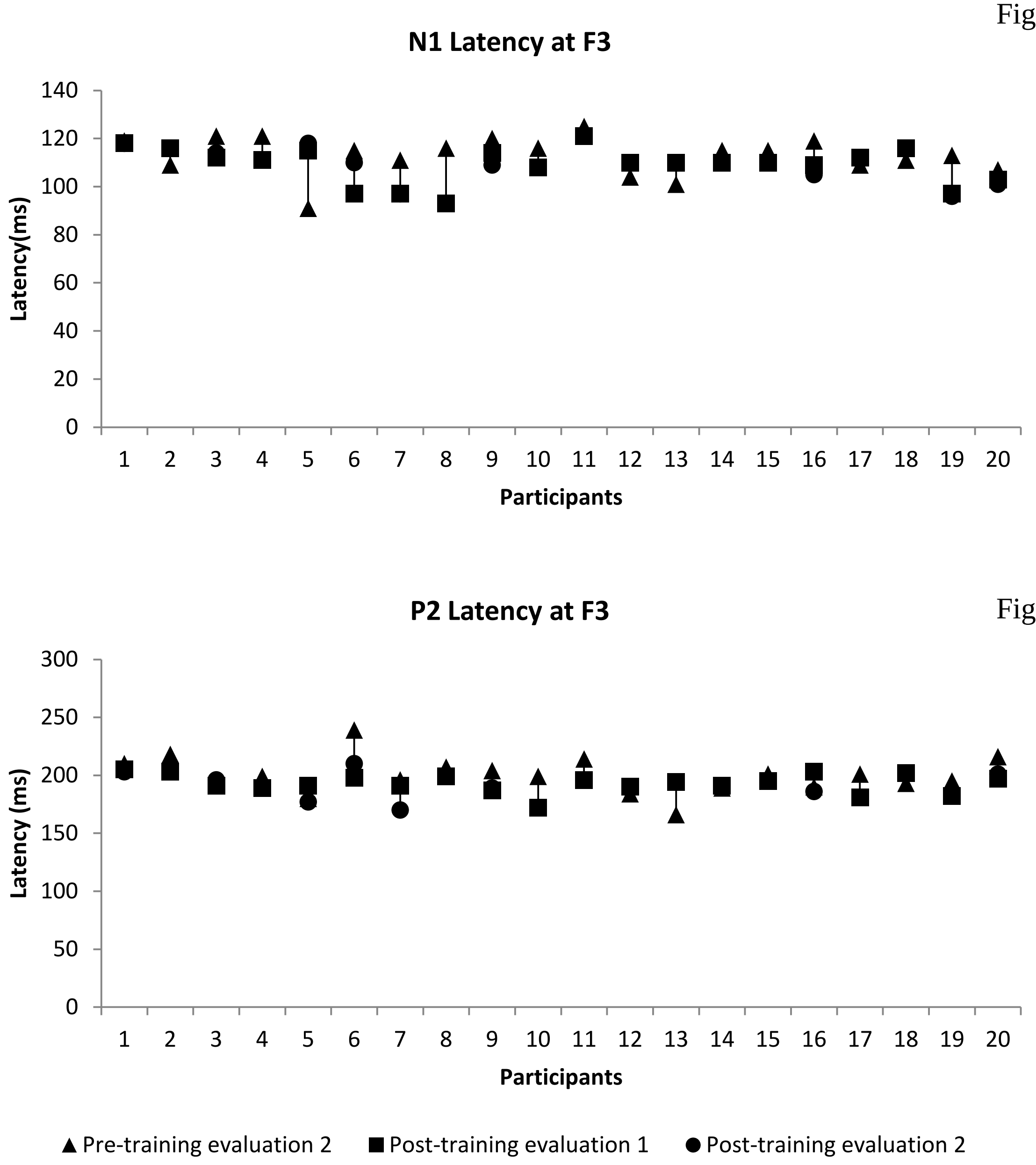


Figure 4.9. Individual latencies of (a) N1 and (b) P2 for /ṭa/ at F3 for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.10 a

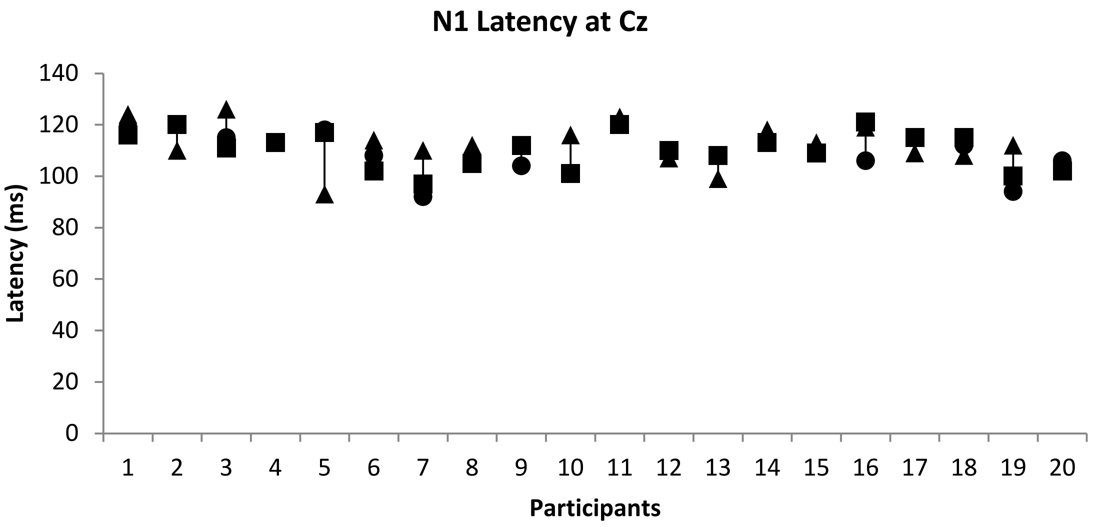


Figure 4.10 b

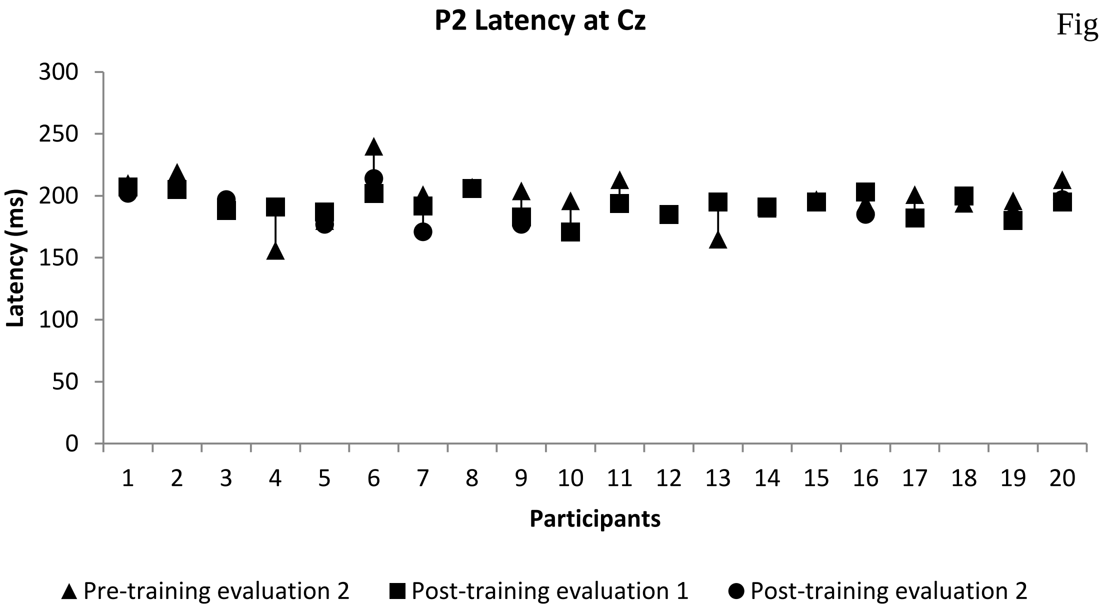


Figure 4.10. Individual latencies of (a) N1 and (b) P2 for /ṭa/ at Cz for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.11 a

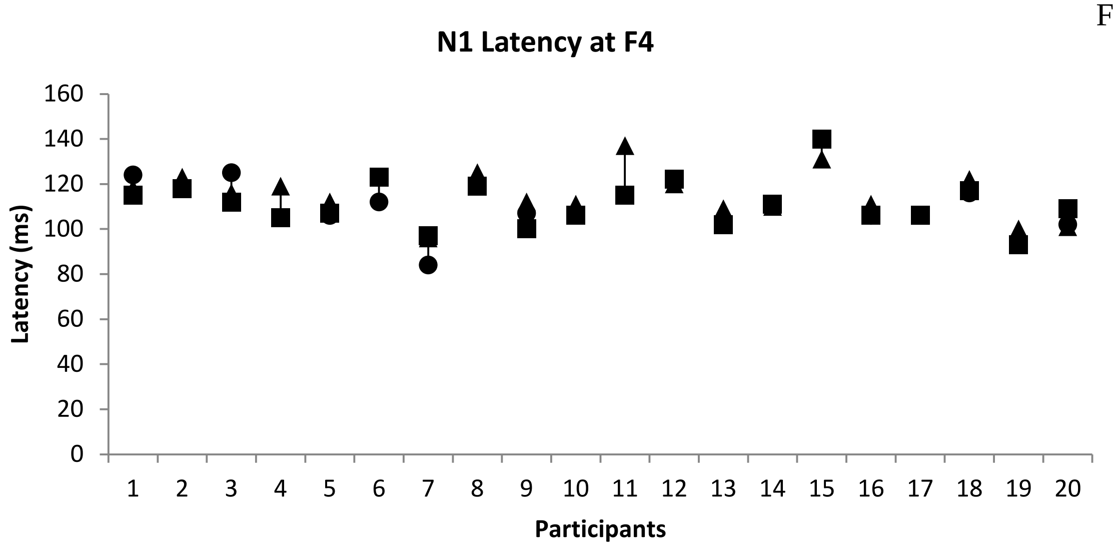


Figure 4.11 b

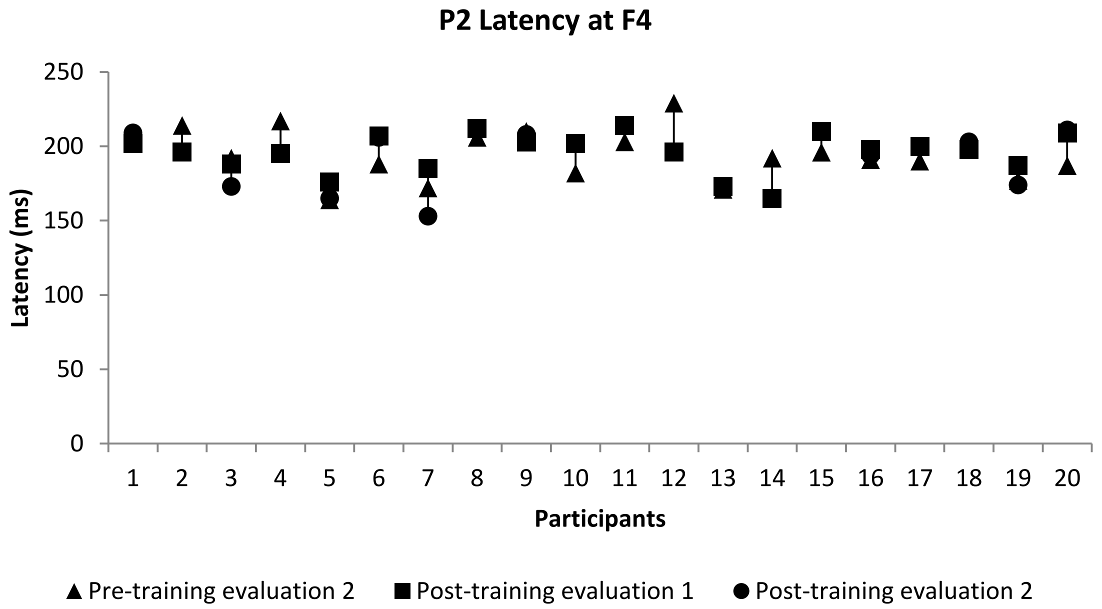


Figure 4.11. Individual latencies of (a) N1 and (b) P2 for /ḍa/ at F4 for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.12 a

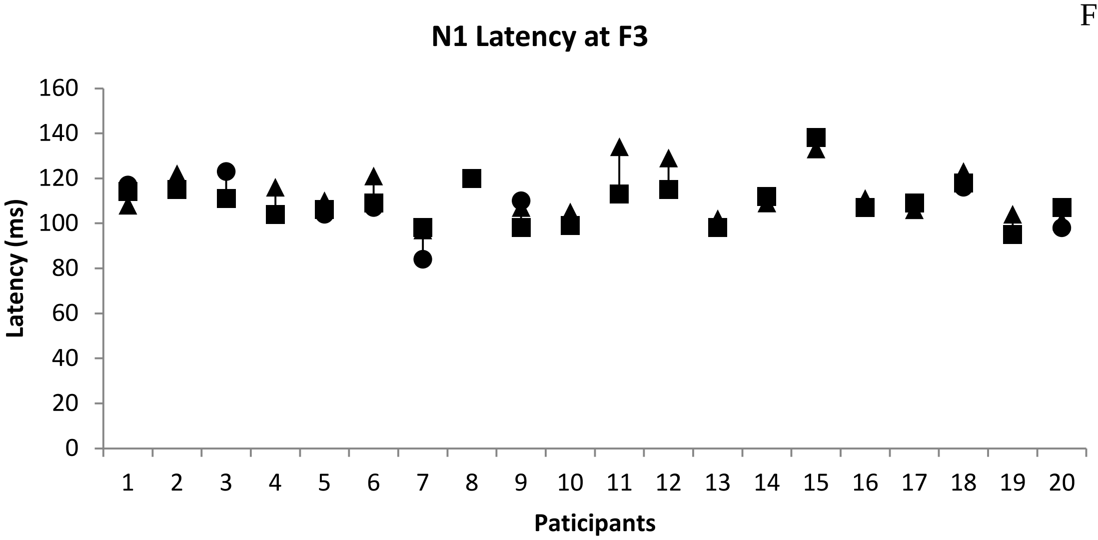


Figure 4.12 b

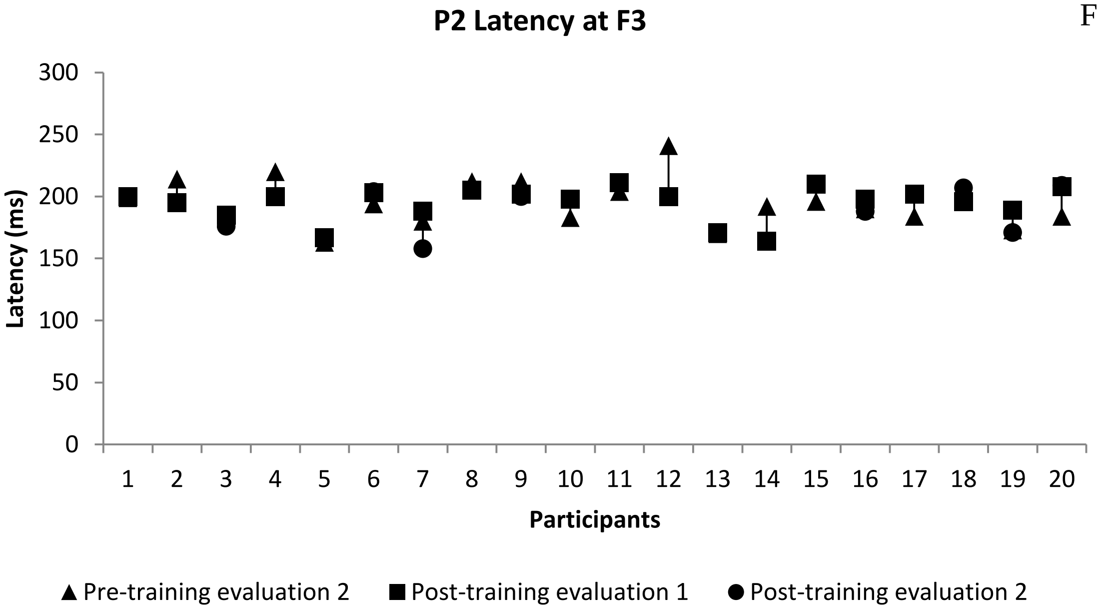


Figure 4.12. Individual latencies of (a) N1 and (b) P2 for /ḍa/ at F3 for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.13 a

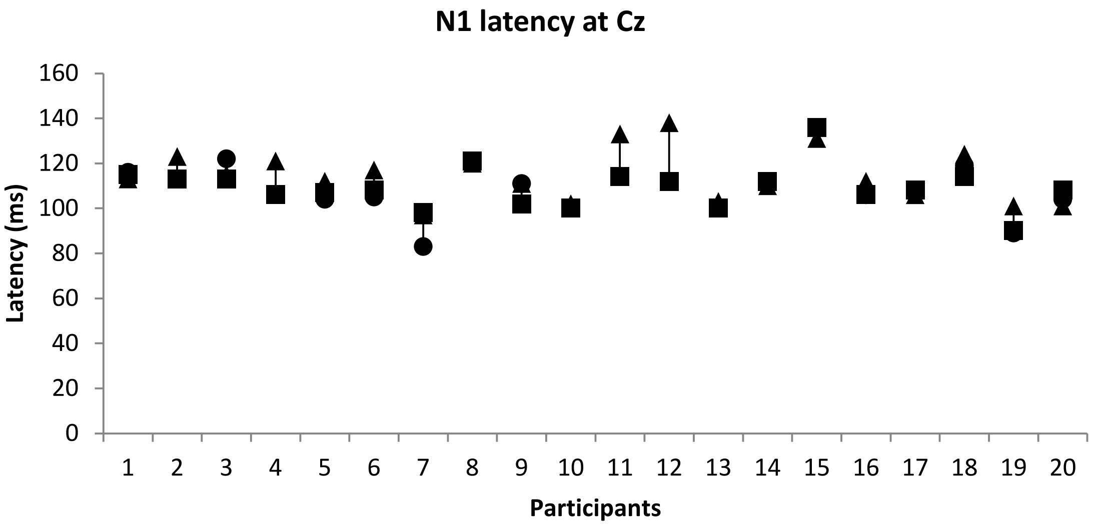


Figure 4.13 b

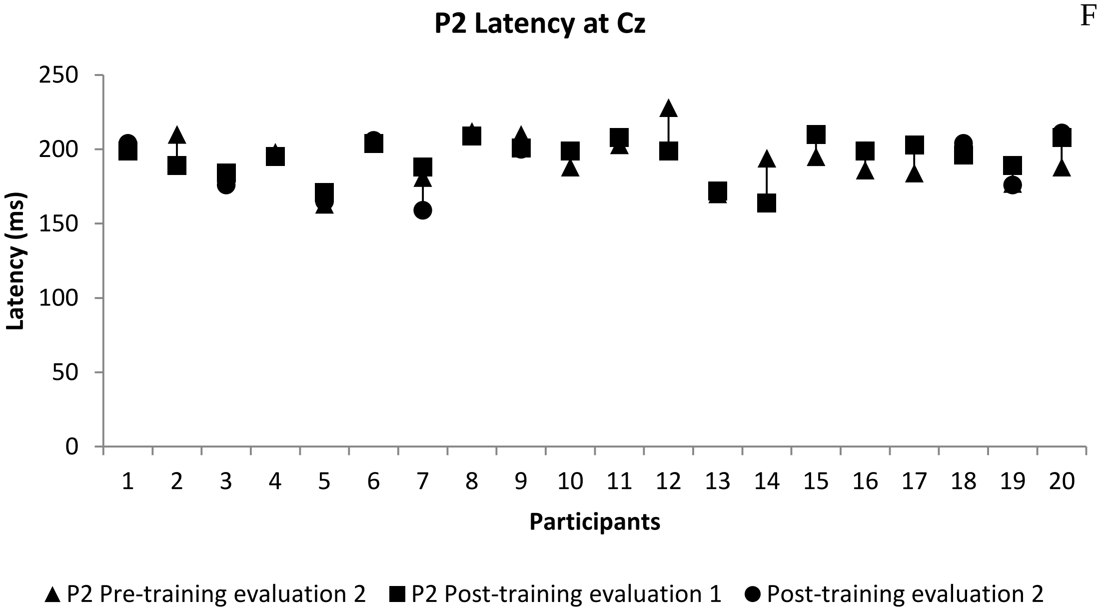


Figure 4.13. Individual latencies of (a) N1 and (b) P2 for /ḍa/ at Cz for pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

4.3.9.2 Effect of temporal resolution training on the amplitude of LLR.

The mean, median, and standard deviation of the amplitude of the N1-P2 complex of LLR for /ṭa/ and /ḍa/ are shown in Table 4.16 and Table 4.17. It can be observed from the table that the mean amplitude showed an increase after the temporal resolution training. Further analyses were carried out to see if this change was significant.

Table 4.16

Mean, median and standard deviation of amplitude of N1-P2 complex in microvolt (µv) for /ṭa/ stimuli

Site	**Response**	**N1-P2 Amplitude (µv)**		
		Mean	**Median**	**SD**
F4	Pre-Training Evaluation- 2	3.27	3	1.38
	Post-Training Evaluation- 1	3.56	3.03	1.53
	Post-Training Evaluation- 2	4.09	3.74	1.86
F3	Pre-Training Evaluation- 2	3.61	3.42	1.66
	Post-Training Evaluation- 1	3.67	3.39	1.48
	Post-Training Evaluation- 2	4.81	4.19	2.22
Cz	Pre-Training Evaluation- 2	4.21	3.87	1.64
	Post-Training Evaluation- 1	4.35	4	1.81
	Post-Training Evaluation- 2	5.76	4.95	2.39

Table 4.17
Mean, median and standard deviation of amplitude of N1-P2 complex in microvolt (µv) for /ḍa/ stimuli

Site	**Response**	**N1-P2 Amplitude (µv)**		
		Mean	**Median**	**SD**
F4	Pre-Training Evaluation-2	3.37	3.42	1.28
	Post-Training Evaluation-1	3.54	3.55	1.21
	Post-Training Evaluation-2	4.19	3.93	1.43
F3	Pre-Training Evaluation-2	3.59	3.39	1.39
	Post-Training Evaluation-1	3.82	3.7	1.49
	Post-Training Evaluation-2	4.96	4.47	1.16
Cz	Pre-Training Evaluation-2	4.09	3.79	1.38
	Post-Training Evaluation-1	4.39	4.4	1.36
	Post-Training Evaluation-2	5.55	5.32	1.63

Findings immediately after cessation of training on LLR amplitude: The effect of temporal resolution training on the amplitude of N1-P2 complex immediately after cessation of training was obtained from a comparison of the amplitudes measured in pre-training evaluation-2 and post-training evaluation-1. A repeated measure ANOVA was performed with stimuli (/ṭa/ & /ḍa/), response acquisition site (F4, F3 and Cz), evaluations (pre-training evaluation-2 and post-training evaluation-1) as independent variable and amplitude of N1-P2 complex as dependent variable. No significant effects of stimuli ($F(1, 9) = 0.24$, $p > .05$) and evaluation ($F(1, 9) = 0.64$, $p > .05$) were observed. In contrast, the response acquisition site showed a significant difference (F(2,

18) = 17.53, $p < .001$). All the interactions were found to be not significant. The Bonferroni correction revealed that when the evaluations were combined the amplitude at Cz was significantly higher than that at F4 ($p < .01$) and F3 ($p < .05$). The amplitude at F3 was in turn significantly higher than that at F4 ($p < .05$). To establish in which of the evaluations and in which sites the amplitude of the responses were significantly different, paired-sample t-tests were done. The results of this pair-wise comparison failed to show a significant difference between the amplitude of N1-P2 complex on the two evaluation at any of the response acquisition sites [F4 ($t = 1.22$, df = 39, $p > 0.05$), F3 ($t = 0.77$, df = 39, $p > 0.05$) & Cz ($t = 1.09$, df = 39, $p > 0.05$)].

Findings one month post cessation of therapy on LLR amplitude: The effect of temporal resolution training on the amplitude of N1-P2 one month after the cessation of training was obtained by comparing the two post-training evaluations. A repeated measure ANOVA revealed no significant effect of stimuli ($F(1, 9) = 0.78$, $p > .05$) with evaluations and response acquisition sites combined and the evaluations ($F(1, 9) = 1.41$, $p > .05$) with stimuli and response acquisition sites combined. A significant effect of response acquisition site ($F(2, 18) = 28.91$, $p < .001$) was found with stimuli and responses combined. Pair-wise comparison with Bonferroni correction showed that the amplitude at the Cz site was significantly different from that at F3 and F4.

Figure 4.14 a

Figure 4.14 b

Figure 4.14 c

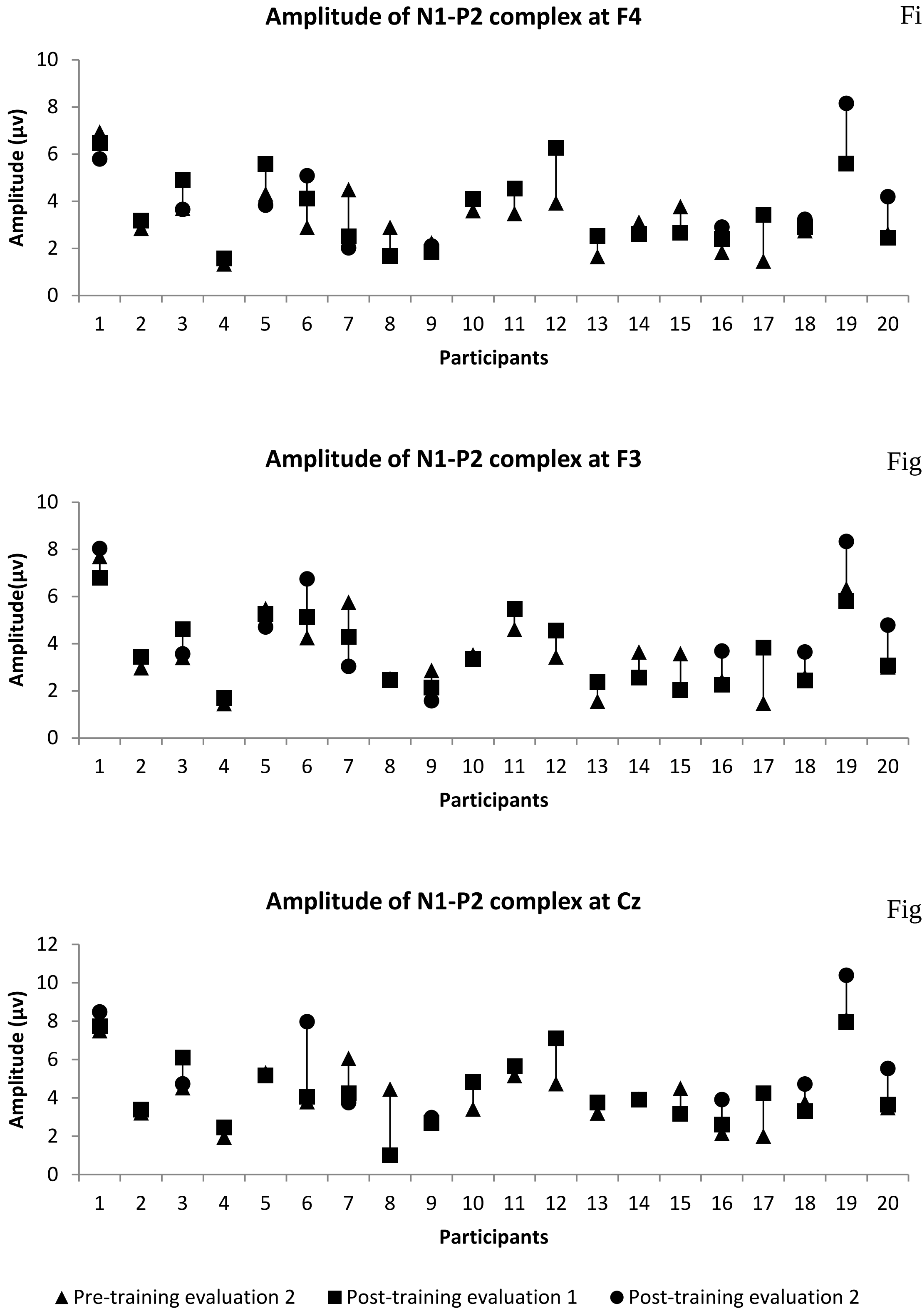


Figure 4.14. Individual amplitude of N1- P2 complex for /ṭa/ at (a) F4, (b) F3 and (c) Cz across pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

Figure 4.15 a

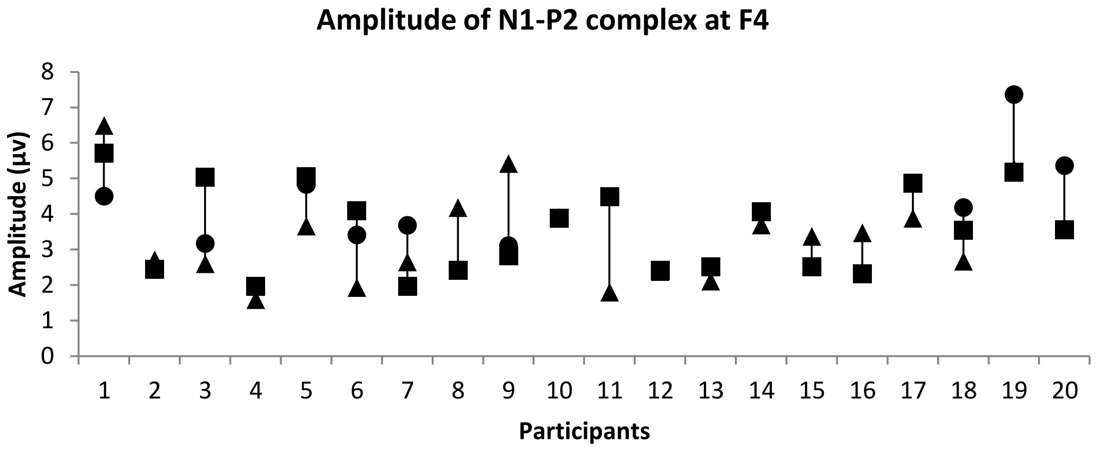


Figure 4.15 b

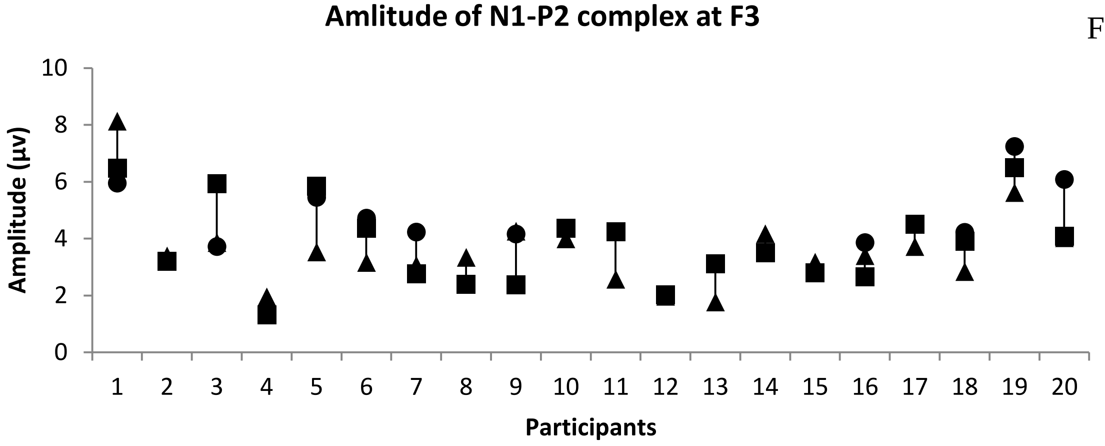


Figure 4.15 c

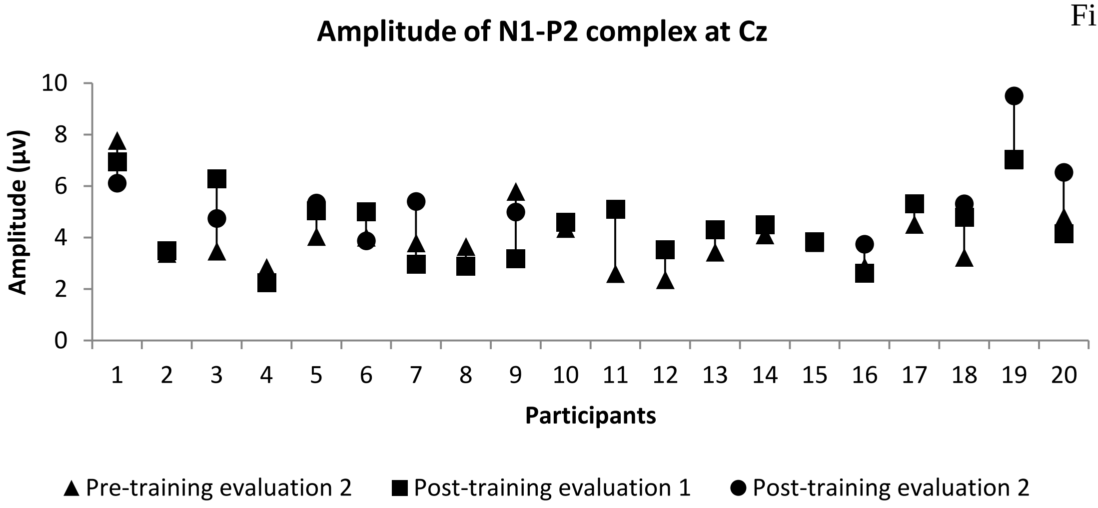


Figure 4.15. Individual amplitude of N1- P2 complex for /ḍa/ at (a) F4, (b) F3 and (c) Cz across pre-training evaluation-2, post-training evaluation-1 and post-training evaluation-2.

From the results, it can be construed that the performances in the tests of auditory processing and auditory memory and sequencing showed changes after temporal resolution training. The changes that occurred were in terms of better scores in most of these tests. The tests that showed improved performances include GIN, GDT, DPT, DCV, and SPIN-K. Improvement was seen in only auditory memory span of the KAMST and not in auditory sequencing span (Table 4.18). In contrast, scores on voicing discrimination word test in Kannada showed no changes. The improvement seen in GIN, DPT, DCV, SPIN-K and auditory memory span was also maintained four weeks after the cessation of temporal resolution training. In addition to the improvement in some of the behavioural tests, the temporal resolution training brought about cortical changes as well. This was in the form of a significant reduction in the mean latencies of N1 but not in P2. Likewise, the amplitude changes in the N1-P2 complex were also not significant.

Table 4.18
Summary of the significance of difference in performance across evaluations (Pre-training evaluation-1, Post-training evaluation-1, & Post-training evaluation-2) for different tests (auditory processing, voicing discrimination, auditory memory)

Test		**Pre-training evaluation-1 and Post-training evaluation-1**	**Post-training evaluation-1 and Post-training evaluation-2**	**Pre-training evaluation-1 and Post-training evaluation-2**
GIN		***	NS	**
GDT		***	**	**
DPT		**	NS	NS
DCV test		**	NS	NS
SPIN-K		***	NS	**
VDWT		NS	NS	NS
KAMST	MS	*	NS	*

	SS	NS	NS	NS

Note. * = $p < .05$; ** = $p < .01$; *** = $p < .001$; NS = Not significant; GIN = Gap-In-Noise test; GDT = Gap Detection Test; DPT = Duration Pattern Test; DCV = Dichotic CV test; KAMST = Auditory memory and sequencing test in Kannada; MS = Memory span; SS = Sequencing test; SPIN-K = Speech perception in noise in Kannada; and VDWT = Voicing Discrimination Word Test in Kannada.

Chapter 5

DISCUSSION

The results of the current study that aimed to determine the efficacy of auditory temporal resolution training (ATRT) in older adults with near normal hearing, are discussed for different central auditory processes (temporal resolution, temporal patterning, binaural integration, & auditory separation / closure), voicing discrimination as well as auditory memory and sequencing. Initially, the difference in performance in the two age groups (55 to 64;11 & 65 to 74;11 years) are discussed. Prior to discussing the effect of the training programme, the difference in scores of the left and right ears for each of the tests as well as the performance of the older adults in relation to available norms are discussed. The effect of ATRT are discussed with regards to the performance of the participants on the Gap-In-Noise test (GIN), Gap Detection test (GDT), Duration Pattern Test (DPT), Dichotic CV test (DCV), Speech-Perception-in-Noise test in Kannada (SPIN-K), Kannada Auditory memory and sequencing test (KAMST), and Voicing discrimination word test in Kannada (VDWT).

5.1 Effect of age on test performance (auditory processing, voicing discrimination, & auditory memory)

The comparison of the two age groups in the present study revealed no significant difference between them. No deterioration with advance in age was observed for the performance on the auditory processes assessed (temporal processing, binaural integration, and auditory separation/closure), voicing discrimination as well as auditory memory and sequencing. This is in contrast to the findings of Kumar and Sangamanatha (2011) who reported that difficulty in certain temporal processing (gap detection, duration discrimination & modulation detection thresholds) was noticeable in individuals above the age of 40 years while deficits on duration pattern scores was noticed only after the age of 60 years. The difference in the findings of the two studies could be due to the methodology used. In the current study, tests of temporal processing were administered monaurally whereas Kumar and Sangamanatha used binaural assessment. It has been noted that performance on monaural presentation results in less deterioration comparison to binaural processing (Szymaszek et al., 2006). Based on the findings of the current study, null hypothesis 1, *"There is no significant difference between the performance of the two age groups on auditory processes [temporal resolution (2 tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing"*, is accepted.

5.2 Comparison of performance on behavioural tests in pre-training evaluation-1 and pre-training evaluation-2

The performance on the tests of auditory processing (GIN, GDT, DPT, DCV, SPIN-K), voicing discrimination and auditory memory did not change when no intervention was provided. This is evident from the comparison of the two pre-training evaluations (pre-training evaluation-1 & pre-training evaluation-2). This occurred immaterial of the test that was administered. Thus, it can be construed that no external variables influenced the performance of the individuals and that their scores on the tests remained stable when evaluated over a period of time when no intervention is provided. These results also established that the test-retest reliability of all the tests that were administered in both the evaluations were high. Hence, null Hypothesis 2, *"There is no significant difference in performance on auditory processes [temporal resolution (2* *tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing without intervention/training”,* is accepted.

5.3 Performance of the participants on auditory processing, voicing discrimination, and auditory memory

The performance of the older adults in relation to available norms is discussed to shed light on the difference in abilities between this age group and young adults. In addition, comparison of ears of the participants is discussed for each of the tests where ear specific information was obtained. Further, the ATRT programme was found to have varying effects on the behavioural tests and the electrophysiological test that were studied. The effect was observed to depend whether the tests directly evaluated the auditory process for which training was provided (GIN & GDT) or not (Duration Pattern, Speech-Perception-in-Noise, Voicing discrimination word test in Kannada, Auditory memory and sequencing, & LLR). The above are discussed for each of the tests administered.

5.3.1 Temporal resolution performance of older adults:

Temporal resolution was studied using two tests (GIN & GDT). The performance of the older adults in relation to the norms established for young adults, the differences in the performance across the two ears of the older adults and the effect of ATRT training on the gap detection thresholds obtained using the two tests are discussed below.

Performance in relation to norms of young adults: The performance of the older adults prior to training was poorer than the published norms for younger adults on the two tests of temporal resolution, GIN (Aravindkumar et al., 2012) and GDT (Shivaprakash, 2003). This indicates the presence of temporal resolution deficits in these individuals in spite of normal / near normal hearing sensitivity.

Similar results were also reported by researchers using gaps embedded in noise stimuli (He et al., 1999; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Vaidyanath & Yathiraj, 2015). This age related deterioration in temporal resolution abilities was also found using mismatch negativity (MMN) by Bertoli et al. (2002). However, the findings are in contrast to that of Moore et al. (1992) and Roberts and Lister (2004) who reported that gap detection thresholds of some older adults were similar to that of younger adults using pure-tones and white noise respectively.

From the findings of the present study and those reported in the literature on gap detection thresholds of older adults, it can be inferred that most individuals in this age group do have difficulties in gap detection. This occurs despite normal / near normal hearing sensitivity. This highlights the need to provide training to counter the adverse effects of such a problem.

Performance across the ears: The gap detection thresholds of the right and the left ear, obtained using GIN and GDT, were found to not differ significantly. This is in congruence with the findings of Shivaprakash (2003) in young adults using GDT and Aravindkumar et al. (2012) using GIN. This is also similar to the reports of other researchers (John et al., 2012; Schneider et al., 1994) who did not report of any significant difference between the performances of the two ears in older adults. The absence of an ear difference can be ascribed to nonverbal stimuli (noise & tones) being processed bilaterally in the auditory cortex, as reported by Binder et al. (2000) and Mirz et al. (1999). The stimulation of the two hemispheres in a similar manner could have led to the two ears performing in a similar way, resulting in no significant difference between them.

The above findings are in contrast to those reporting of right ear advantage in gap detection especially for broadband noise (Sininger & de Bode, 2008; Sulakhe, Elias, & Lejbak, 2003). According to Sulakhe et al. (2003) and Sininger and de Bode (2008), a right ear advantage in gap detection was observed as the left hemisphere has been reported to better code temporal- related information.

Thus, it can be observed that there is no consensus in the literature regarding ear symmetry for gap detection. However, the majority of studies indicate that gap detection is similar across the two ears. The findings of the present study are similar to the majority of studies that report of no ear difference.

Effect of ATRT training: The findings of the current study indicated that temporal resolution training had a significant positive effect on temporal resolution abilities of the older adults, measured using GIN and GDT. This improvement can be attributed to the effect of the ATRT programme and not due to any co-existing variables. This can be substantiated as without any intervention, no change in performance was observed during the two pre-training evaluations. The intervention could have enabled the older adults to attend better to short-duration gaps that they probably tended to ignore with advance in age. The ATRT programme probably stimulated their superior temporal gyrus near the primary auditory cortex area, which has been reported to be the areas responsible for detection of small duration gaps in auditory stimuli by Heinrich, Alain, and Schneider (2004), thereby brining about improvement in the gap detection thresholds.

The observed changes with temporal resolution training can also be attributed to better abilities to overcome the effect of temporal masking. It has been reported that older adults required longer gap between masker and signal to detect the presence of a signal (Elliott, 1962; Gehr & Sommers, 1999; Gifford et al., 2007; Newman & Spitzerb, 1983; Walton et al., 1999). In a gap detection task the preceding marker is likely to mask the gap succeeding it, thereby enabling older adults to perceive only longer gaps. With temporal resolution training, this masking effect may have reduced leading to better gap detection thresholds.

Additionally, in spite of a difference in the pattern of gaps used for the ATRT programme and GIN, the gap detection thresholds were found to improve in GIN. It can thus be inferred that training using gaps that occur at regular intervals, similar to that present in GDT, can result in generalised learning of random gaps that occurs in GIN.

Further, in the present study it was found that the temporal resolution abilities continued to be significantly better than the pre-training evaluations. This improvement was seen despite gap detection thresholds obtained using GDT showing a significant deterioration one month after the cessation of training. However, with GIN such a deterioration did not occur, although it is considered a more difficult test compared to GDT by Vaidyanath and Yathiraj (2015). A possible reason for the significant reduction in scores for GDT and not for GIN could be due to exposure to random gaps present in speech. This could have helped in the maintenance of random gap thresholds of GIN. To prevent such deterioration, instead of abruptly stopping training, it is recommended that training should be continued with the frequency of training sessions and the duration of the sessions being gradually reduced.

It can be observed from Figure 4.1 (a, b) and Figure 4.2 (a, b) that with temporal resolution training the gap detection thresholds improved and were found to be similar to that of young adults (depicted by the shaded area). In addition, from the figures it can be observed that although the majority of participants displayed improvement in gap detection thresholds, the amount of change varied from one participant to another. Thus, the improvement in the gap detection thresholds resulted in a reduction in the number of older individuals failing the two tests of temporal resolution. This number reduced from 17 to 5 in GIN and 16 to 3 in GDT. Among those who continued to fail the tests, two failed both tests (participant no. 12 and 20). These participants had larger gap detection thresholds compared to all the other participants on GIN. While they did show improvement in gap detection thresholds, this improvement was not sufficient to reach the norms for young adults.

The results bring to light that temporal resolution training enabled the majority of the participants to perform similar to young adults, thus making it possible for them to pass the temporal resolution tests that they failed before the training. Since all the participants did not pass the two temporal resolution tests despite showing some benefit, it indicates that some of them probably required longer duration of training to attain scores similar to young adults.

In addition to the variability in the improvement seen in the gap detection thresholds, variability was also observed in the number of training sessions required by the older adults to reach the criterion for termination of ATRT training. The number of training sessions ranged from 7 sessions to a maximum of 13 sessions. The six participants who did not reach the norms of the two tests also required above 9 training sessions, with most of them requiring more than 11 sessions.

Therefore, null hypotheses, *3a "Temporal resolution training has no significant effect on performance in tests of temporal resolution (GIN & GDT)"* is rejected. On the other hand, null hypothesis, *4a "Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in tests of temporal resolution (GIN & GDT)"* is accepted.

5.3.2 Temporal patterning performance of older adults:

The effect of age on the temporal patterning abilities and the comparison of the performance across the two ears of the participants are discussed below. Additionally, the effect of ATRT training on scores on temporal patterning, assessed using DPT, is also discussed.

Performance in relation to norms of young adults: Temporal patterning abilities of the older adults in the present study before training were found to be poorer than that reported for younger adults by Gauri (2003). This can be deduced from the poorer scores of the older individuals in comparison to the norms for younger adults obtained by Gauri (2003), depicted in Figure 4.3. The poorer performance of the older adults compared to young adults on tests of temporal patterning is in line with studies reported in literature

(Fink et al., 2005; Fitzgibbons et al., 2006; Newman & Spitzerb, 1983; Szymaszek et al., 2006; Trainor & Trehub, 1989). The reasons reported for the poor temporal patterning performance of the older adults are uncertainty in the perception of the stimuli (Trainor & Trehub, 1989) and slowing of temporal information processing with ageing (Fink et al., 2005; Kumar & Sangamanatha, 2011; Szymaszek et al., 2006). However, these findings are in contrast to that reported by Fitzgibbons and Gordon-Salant (1998) who failed to obtain any significant effect of age. This probably occurred as they used a temporal order discrimination task rather than temporal order identification. According to them, the lesser complexity of the discrimination task used could have led to the observed results.

Performance across ears: The temporal patterning abilities of the two ears did not differ significantly in the participants of the present study. A similar result was also reported by Gauri (2003) and Musiek, Baran, et al. (1990) for young adults. This indicates that the deterioration in the temporal patterning abilities that occurs with ageing is similar across the two ears. These results were similar to that obtained for temporal resolution where a significant difference between the performances of the two ears was not found. As mentioned earlier, nonverbal stimuli are processed in both the hemispheres of the brain. With ageing, both hemispheres were probably affected in a similar manner, resulting in similar deficits in the ability to processes temporal order of the signals. This would have resulted in the lack of significant difference between the two ears.

Effect of ATRT training: The temporal patterning abilities showed significant improvement after the administration of ATRT programme. This improvement is evident from the mean/median scores of the duration pattern test (Table 4.7). Further, following training there was a marginal increase in the number of older individuals who achieved scores similar to the norms of young adults given by Gauri (2003). However, the extent to which the temporal patterning scores increased following training varied from one participant to another. A few of the participants show no change in the scores, as evident from the overlapping points in Figure 4.3 (a, b). The lack of change in performance in these participants (participants 8, 10, 11, 13, 14, 15, 17 & 19) can be attributed to a ceiling effect since their pre-training performance was already approximated the maximum attainable score. Hence, it can be inferred that those participants who had temporal pattern processing difficulties did benefit from the training programme and showed marked improvement subsequent to it (participants 1, 2, 3, 6, 9, 12, 18 & 20).

The variability in the performance of the participants was also evident depending on whether the pre- and post-training evaluations were compared for the 10 participants who partook throughout the study or whether the data of all 20 participants were evaluated. While a significant difference was evident between pre-training evaluation-1 and post-training evaluation-1 with the 20 participants, it was absent when the analysis was done with the 10 participants. In addition, there was no significant improvement between pre-training evaluation-1 and post-training evaluation-2. A probable reason for this discrepancy in findings could be the variability in performance of the participants across the evaluations. From the raw data, it was observed that the participants who showed an improvement in the duration pattern test did not participate in the post-training evaluation-2. Seven (participants 1, 5, 7, 9, 16, 19, & 20) out of the 10 participants who were evaluated in post-training evaluation-2 were those who obtained a ceiling effect, i.e. high scores in pre-therapy evaluation-1 (Figure 4.3 a, b). This could have led to no significant difference between the pre-training and post-training evaluations. However, from the performance of the 20 participants soon after the training, it can be inferred that the ATRT programme does have a positive effect on pattern perception. Had those who had no ceiling effect been tested during evaluation-2, a positive impact of training would have been seen in this post-training evaluation also.

The improvement in temporal patterning performance following temporal resolution training has support from the findings of Morais et al. (2015). They observed improvements in temporal patterning abilities in older adults in addition to improvements in auditory closure, dichotic listening, and temporal resolution following ‘acoustically controlled auditory training’. Thus, it can be inferred that training in one process can result in improvement in another related process.

Thus, null hypothesis *3b “Temporal resolution training has no significant effect on performance in a test of temporal ordering (Duration Pattern Test)”* is rejected and null hypothesis *4b “Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in a test of temporal ordering”* is accepted.

5.3.3 Binaural integration performance of older adults:

Binaural integration abilities were found to be affected in the older adults evaluated in the current study. This difficulty was found to be positively influenced by the administration of the temporal resolution training. These findings are discussed below.

Performance in relation to norms of young adults: The Dichotic CV scores (right single correct, left single correct, & double correct scores) of the older adults were found to be poorer than that reported by Prachi (2000) for young adults. Deterioration in the dichotic speech perception with age has also been reported for dichotic sentences (Jerger et al., 1995; Jerger et al., 1994), and NU-6 monosyllabic words presented dichotically (Roup et al., 2006). This deterioration in dichotic speech perception is reported to be due decline of cognitive factors like memory, inefficient inter-hemispheric transfer of information in the corpus-callosum (Jerger et al., 1994) and progressive atrophy or progressive loss of myelination of corpus callosal fibres (Jerger et al., 1995).

Further, in the current study, the right ear advantage obtained by the older adults was more than that reported by Prachi (2000) for younger adults. While the older adults in the present study had an advantage of 2.85, that reported for younger adults by Prachi was 1.64. On observation of the raw scores of the older adults, it was noted that this increased right ear advantage was on account of a decrease in the scores of the left ear, with a lesser decrease in the right ear scores. This increased right ear advantage due to a decrease in left ear scores was also reported by Jerger et al. (1994) and Jerger et al. (1995). This decrease in the left ear scores has been considered to occur due to the effect of ageing on the pathway carrying information from the left ear and the inter-hemispheric transfer of information (Jerger et al., 1994). This finding is in contrast to the findings of Gelfand et al. (1980) who reported similar right ear advantages between young and older adult groups for dichotic CV stimuli. Gelfand et al. (1980) suggested that the auditory mechanism responsible for the right ear advantage was not affected by age leading to similar right ear advantages in the two groups.

Effect of ATRT training: Like the other tests, the binaural integration abilities assessed using the Dichotic CV test scores showed improvement after the ATRT programme. This is evident from the scores in Table 4.7. Enhancements in single correct scores of the right and left ears as well as the double correct scores were observed. Despite these improvements, in some participants the scores did not reach the norms for young adults given by Prachi (2000). This difference in performance is noticeable in Figure 4.4 (a, b, c). Additionally, the amount of improvement in scores was variable across the participants, similar to that seen in the other tests that were administered. Further, the improvement in the scores observed immediately after the cessation of training, was maintained 4 weeks after the cessation of training. This is shown by the absence of a significant difference between the scores in the two post-training evaluations.

From the improved performance in the Dichotic CV test following the ATRT programme, it can be surmised that training in auditory temporal resolution does have a positive impact on binaural integration. This probably occurred since the training led to an improvement in perception of auditory temporal cues important for consonant recognition in these older adults. The other possible reason for this could be the increased alertness of the older adults to the stimuli presented following the training.

The improvement seen in the binaural integration abilities of older adults following ATRT training is in consensus with the findings of Morais et al. (2015). They reported that their older adults who were trained using ‘acoustically controlled auditory training’ demonstrated improvement in dichotic listening, in addition to improvement in auditory closure, temporal ordering and temporal resolution.

From the above finding, it can be concluded that null hypothesis *3c, "Temporal resolution training has no significant effect on performance in test of Binaural integration (Dichotic CV test)"* is rejected. On the other hand, null hypothesis *4c, "Temporal resolution training has no significant difference on performance 4 weeks after cessation of training in a test of binaural integration (Dichotic CV test)"* is accepted.

5.3.4 Auditory separation/closure performance of older adults

The effect of age, the difference in the performance of the two ears of the older adults, and the effect of ATRT training on auditory separation / closure abilities were studies in the current study. The auditory separation / closure abilities of the participant are discussed based on their performance on SPIN-K.

Performance in relation to norms of young adults: The mean and median scores of the older adults before the training on the Speech-Perception-in-Noise test in Kannada (SPIN-K) were considerably lower than the scores reported by Kalikow et al. (1977) for young adults. This can be observed from Figure 4.5 (a, b) that indicates that the scores of the older adults in pre-training evaluation-1 were below the norms of younger adults, represented by the shaded area.

The poorer performance of the older adults in comparison to younger adults is supported by studies reported literature (Dubno et al., 1984; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008; Wong et al., 2010). Such poorer performance has been reported in studies using different speech materials (Dubno et al., 1984; Frisina & Frisina, 1997; Pichora-Fuller et al., 1995), background noise (Prosser et al., 1991; Russo & Pichora-Fuller, 2008), and signal-to-noise ratios (Gelfand et al., 1986). The reasons reported by these authors for the poor performance include auditory dysfunction associated with the cochlear mechanisms, deterioration in short-term memory (Dubno et al., 1984; Pichora-Fuller et al., 1995) and poor abilities to extract features required for speech perception (Dubno et al., 1984).

The poorer speech perception in the presence of noise observed in these older adults could have been due to poor functioning of the medial olivocochlear system, as noted by Mukari and Mamat (2008). They reported a correlation between the medial olivocochlear system functioning and speech recognition in presence of noise. They also reported that in older adults the contralateral suppression of distortion product otoacoustic emissions was significantly lower, especially in the high frequencies compared to the younger adults considered in their study.

Performance across ears: The performance of the two ears on SPIN-K was found not to be significantly different. This lack of significant difference indicates that the processing of speech in the presence of noise was equally affected in the two ears. Wong, Uppunda, Parrish, and Dhar (2008) found bilateral activation of superior temporal gyrus while individuals listened to speech presented in presence of noise, indicating that both hemispheres are responsible for speech perception in noise. The findings of the current study indicate that with ageing these cortical areas are symmetrically affected, resulting in similar performance across the two ears. A similar performance of the two ears has also been reported by Mukari and Mamat (2008).

Effect of ATRT training: The scores on SPIN-K, after training using ATRT programme was found to be significantly better in comparison to the scores before training. In addition to the SPIN-K scores, the positive effect of the ATRT programme on perception of speech in the presence of noise was also evident from the subjective reports of four of the participants. These participants reported of decreased difficulty while listening to SPIN-K after the training, in comparison to their difficulty prior to the training.

The ATRT programme not only helped improve perception of speech in the presence of noise immediately after the training, but also enabled maintenance of this improvement 4 weeks after the cessation of the training. Although a slight deterioration was observed in the scores 4 weeks post-training, though not significant, the scores obtained in post-training evaluation-2 remained significantly higher compared that obtained in pre-training evaluation-1.

After training, the scores of some of the participants (N = 9) improved to reach the scores of young adults. However, in some the participants who showed improvement in performance (N = 6), the scores continued to be below the normative value range. From this, it can be construed that the effect of ATRT programme was variable, with some participants improving more in comparison to others. The variability in the improvement in the scores seen after the temporal resolution training could also be due to the variations in the amount of difficulty experienced by the older adults. From Figure 4.5 (a, b) it can be noted that the amount of improvement shown by the individual after temporal resolution training was not dependent on their initial difficulty. The improvement was observed not only in those individuals who had relatively better SPIN-K scores but also in individuals with poorer SPIN-K scores.

The improvement seen in SPIN-K scores with training in temporal resolution is in consensus with studies reported in literature that indicated that a relation exists between gap detection thresholds and speech perception in presence of noise (Phillips et al., 2000; Snell & Frisina, 2000; Snell et al., 2002). According to Phillips et al. (2000), reduced temporal resolution abilities contributed to difficulties in syllable recognition in the presence of noise. Thus, it can be inferred that an improvement in the temporal resolution ability following training can lead to improvement in speech recognition in the presence of noise. This probably occurred since an improvement in temporal resolution ability would have enabled the older adults to utilise short duration cues available in speech, thereby improving the intelligibility of the speech signal presented in the presence of background babble. This reasoning can be corroborated with the findings of Phillips et al. (1997) who reported that across-channel gap detection (gap detection with the leading and training markers having different frequencies) resembled perception of VOT cues in speech. Although the current study utilised gap detection training with leading and training markers having similar frequencies, it can be inferred to have a similar effect as the stimuli used by Phillips et al. This is based on the findings of Heinrich et al. (2004) who found that at the auditory cortical level, significant differences between with-in and across-channel gap detection did not occur when measured using MMN. Thus, it can be construed that ATRT training, which resulted in an improvement in temporal resolution abilities, could have also helped in improving the perception of these VOT cues in speech that in turn could have led to an improvement in SPIN-K scores.

Hence, null hypothesis 3d, *"Temporal resolution training has no significant effect on performance in a test of auditory separation*/closure (Speech-Perception-in-Noise test in Kannada)" is rejected. With reference to the maintenance of the effect of training, null hypothesis 4d *"Temporal resolution training results has no significant difference on performance 4 weeks after cessation of training in a test of auditory separation/closure (Speech-Perception-in-Noise test in Kannada)"* is accepted.

5.3.5 Voicing discrimination performance of older adults

The outcome of the analyses regarding the performance of voicing discrimination abilities of the two ears of the participants are discussed below. Additionally, the influence of ATRT training on the performance in the 'Voicing discrimination word test in Kannada', developed in the current study, is also discussed.

Performance across ears: The performance of the two ears of the participants of the current study was observed to be identical on the 'Voicing discrimination word test in Kannada'. This symmetry in performance in the two ears was evident without as well as with training. The symmetry was as expected since monaural speech discrimination scores are known to result in similar performance in the left as well as right ear. The study demonstrates that such symmetry that is typically noted in young adults is maintained with ageing.

Effect of ATRT training: Voicing discrimination abilities assessed using the 'Voicing discrimination word test' did not show any changes after temporal resolution training. The performance across the three evaluations did not show any significant difference. The lack of improvement in the scores of the 'Voicing discrimination word test in Kannada' is also indicated in Figure 4.7 (a, b). It can be observed from the figure that the performance of most of the older adults approximated the maximum possible score on the test with marginal change in these scores across evaluations. Due a ceiling effect on the scores prior to the training, there was not much scope to record any improvement.

The findings indicate that the task of discriminating voicing differences at word initial and medial position was not difficult for the older adults. This could have occurred since they may have utilised redundant cues present within the consonants as well as coarticulated cues. It is possible that on a more taxing test with multiple redundant cues being removed, the impact of training will be seen on voicing perception. It needs to be studies if making the task more difficult by evaluating word discrimination testing in the presence of noise, testing word identification or phoneme identification instead of discrimination, can identify voicing difficulty more effectively, prior to training.

Therefore, null hypothesis *3e, "Temporal resolution training has no significant effect on performance in the 'Voicing discrimination word test in Kannada'"* is accepted. The null hypothesis *4e, "Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in voicing discrimination word test in Kannada"* is also accepted.

5.3.6 Auditory memory and sequencing performance of older adults

The effects of ATRT training on auditory memory and sequencing abilities are discussed below. Prior to that, the effect of age on the auditory memory and sequencing abilities are discussed.

Performance in relation to norms of young adults: The auditory memory and sequencing abilities of the older adults were poorer than the norms reported by Yathiraj and Vijayalakshmi (2006). This can be inferred from the scores in Table 4.9 and Figure 4.6 (a, b). The reduced memory abilities in older adults observed in the current study are supported in literature (Grady & Craik, 2000; Old & Naveh-Benjamin, 2008). Some of the reasons noted for the reduced memory abilities in older adults include the reduction in the processing speed (Salthouse, 1996a, 1996b), reduced attentional resources (Craik & Byrd, 1982), and reduced working memory (Salthouse, Mitchell, Skovronek, & Babcock, 1989).

Effect of ATRT training: From the Table 4.9 and Figure 4.6 (a) it is evident that the auditory memory span changed after temporal resolution training The improvement observed in auditory memory span is also indicated by the presence of a significant difference between the pre-training evaluation-1 and post-training evaluation-2. About 50% of the individuals showed some changes in auditory memory span after undergoing the ATRT programme, with the other 50% showing no change in performance. However, in none of the participants did the auditory sequencing span show any change after training.

The improved auditory memory span after ATRT programme was maintained four weeks after the cessation of training. This is indicated by the absence of significant difference in performance in the two post-training evaluations. The improvement in auditory memory span after training probably occurred as the participants learnt to attend to stimuli more intently. Further, it can be inferred that the memory load of some of the training activities, especially the three and four-sequencing stimulus-sets could have helped in improving their memory skills. The participants would have not only have had to be vigilant in detecting gaps embedded in noise, but recall from memory which of the noise bursts contained the gap. This could have had a positive effect on their memory skills.

The generalization of the improvements following temporal based training on to auditory memory is also reported by Maggu and Yathiraj (2011b). They observed that temporal patterning training not only improved the temporal patterning abilities of the children who were trained but also improved the auditory memory and sequencing abilities of these children.

Thus, it can be inferred that null hypothesis *3f, "Temporal resolution training has no significant effect on performance in a test of auditory memory and sequencing (Kannada auditory memory and sequencing test)"* is accepted for the auditory memory span, but is rejected for the auditory sequencing span. Further, null hypothesis *4f, "Temporal resolution training results has no significant difference on performance 4 weeks after cessation of training in a test of auditory memory and sequencing (Kannada auditory memory and sequencing test)" is accepted.*

5.3.7 Phoneme error pattern in the presence of noise in older adults

The phoneme errors of the participants, prior to and after ATRT training, was analysed from their SPIN-K responses. The same are discussed below.

Effect of ATRT training: A number of phoneme errors, when calculated as percentage of errors after eliminating the ‘no responses’, were observed in the presence of noise prior to the temporal resolution training. Prior to training, the maximum percentage of errors occurred for manner of articulation (77.7%) followed by place of articulation (53.38%) errors and voicing errors (46.62%), in isolation and in combination. The general phoneme error pattern is similar to that noted by Gelfand et al. (1986) who studied phoneme errors of older adults using a nonsense syllable test. They reported a decrease in the information transfer for manner of articulation and place of articulation with age. This decrease was noted more for stop manner of articulation followed by place of articulation information and frication feature information. This deficit was ascribed to deterioration in the use of durational cues with age, which were considered important for the perception of stops and fricative features. Additionally, this decrease was noted to be more in the presence of noise when compared to quiet. According to Gelfand et al., the decrease in the ability of the older adults to utilise perceptual cues available to them was one reason for the errors observed. The effect of age on certain cues that were least robust in the younger adults for perception of speech especially in presence of noise was another reason suggested by them.

The findings of the current study and that of Gelfand et al. (1986) are unlike the typical errors noted in individuals with peripheral hearing loss where place errors are noted to higher than manner and voicing (Bilger & Wang, 1976; Gordon-Salant, 1987;

Revoile & Pickett, 1982; Walden & Montgomery, 1975). The probable reasons for this difference in the order of speech feature difficulties could be due to the acoustic cues that are utilised by the two groups. While those with peripheral hearing loss have been noted to have more problems in spectral resolution, those in the current study had more temporal perception problems. It is known that spectral cues are important for the perception of places cues (Alwan, Jiang, & Chen, 2011; Bilger & Wang, 1976; Blumstein, & Stevens, 1979; Gordon-Salant, 1987; Kewley-Port, Pisoni, & Studdert-Kennedy, 1983; Revoile & Pickett, 1982; Stevens & Blumstein, 1978; Walden & Montgomery, 1975) and temporal cues are important for the perception of manner cues (Alwan, Jiang, & Chen, 2011; Gelfand et al., 1986; Liberman et al., 1956; Ohde & Sharf, 1977; Repp, Liberman, Eccardt & Pesetsky,1978; Wang, 1959).

In the present study, a marked difference in the error pattern before and after training was in the number of 'no responses'. Before the training the participants tended to not respond when unsure of a response, resulting in such responses being maximum compared to other feature errors. A notable change after temporal resolution training was in the reduction in 'no-responses'. After training, the participants attempted to respond more often instead of avoiding responding, as they did before the training. However, the percentage of feature errors (place, manner, voicing or combination of these), calculated as a percentage of errors without including the 'no responses', show only a marginal change with temporal resolution training [manner of articulation (74.84%) followed by place of articulation (54.71%) errors and voicing errors (43.39%)]. Thus, it can be seen that the ATRT programme did not have much of an effect on the percentage of errors noted by the participants as well as the pattern of errors. The manner of articulation errors continued to be higher compared to the place of articulation, which was higher than the voicing errors. Despite the minimal changes in the feature errors after training, with the reduction in the 'no responses' the total number of errors did decrease significantly. The significant reduction in the total number of phoneme errors after training augments the findings that the ATRT programme was helpful in improving the perception of phonemes in the presence of noise. It is possible that if the ATRT programme is provided for a longer duration, a more positive effect on feature errors may be evident.

Further, the reduction in the phoneme errors seen soon after cessation of temporal resolution training, continued to be present 4 weeks after the cessation of training. However, the actual values were not calculated as done for pre-training evaluation-1 and post-training evaluation-2 as the responses were obtained from only 10 of the 20 participants. The errors of these 10 participants at post-training evaluation-1 were different from that of the remaining 10 participants at the same evaluation. Hence, the percentage errors of the 10 participants were not provided for post-training evaluation-2 as a clear picture of the percentage errors would not have been possible. These errors would not have been a completely representative of the errors observed in the earlier observations. However, the pattern of errors remained the same after 4 weeks of cessation of training.

It can be concluded that null hypothesis *3g, "Temporal resolution training has no significant effect on phoneme error pattern in the presence of noise"* is rejected. However, null hypothesis *4g, "Temporal resolution training results has no significant* *difference on performance 4 weeks after cessation of training in phoneme error pattern in the presence of noise"* is accepted.

5.3.8 Effect of auditory temporal resolution training on speech evoked cortical responses

In the current study, the effect of ATRT programme on MMN was evaluated. In addition, the effect of the training programme was studied on the latency and amplitude of LLR responses.

It was found that MMN was absent in the majority of the individuals across the three evaluations. This absence persisted even after an offline removal of baseline EEG activity, to eliminate artefacts. The absence of MMN indicates that at the pre-attentive stage the older adults were not able to discriminate between the two CVs (/ṭa/ & /ḍa/) that differed in terms of voicing. This was observed although these older adults showed good voicing discrimination at a word level, evaluated in the voicing discrimination word test. The presence of additional redundant coarticulatory cues in the word test may have enabled the participants to perceive voicing distinction at the word level. Such redundant cues were not present in the in the CVs used for measuring MMN. This may have led to the absence of the cortical responses. It can also be inferred that the temporal resolution training was not sufficient to eliminate this difficulty in discrimination at the pre-attentive level.

In literature, MMN has been recorded for gaps embedded in a 1 kHz signal by Bertoli et al. (2002) in older adults. It can be speculated that MMNs can be recorded in older adults for gaps in stimuli that are not complex. However, temporal cues present in complex stimuli such as CVs may be difficult for this age group to discriminate and may result in an absence of MMN responses. Thus, the increased complexity in processing of the CV syllables compared to the processing of 1 kHz tone could had led to the absence of MMN in the current study.

MMN has also been recorded in older adults with the use of synthetic speech stimuli (Bellis et al., 2000). However, in the current study, natural stimuli spoken by an adult male was used. The natural stimuli would have been a lot more complex compared to the synthetic stimuli used by Bellis et al., which majorly varied only in terms of onset frequency of F3. This would have made the cues simpler compared to the complex signal used in the current study. This may have resulted in the absence of MMN responses in the current study.

Unlike the responses for MMN, the LLR was present for each of these CVs. The presence of LLR response and the absence of MMN could also be due the difference in generators. It has been reported by Näätänen and Picton (1987) that the generators for MMN and LLR are different. The generators reported for MMN include bilateral secondary auditory cortex including superior temporal gyrus, anterior Heschl’s gyrus and with contributions from prefrontal cortex, thalamus and hippocampus (Alain, Woods, & Knight, 1998; Alho, 1995; Alho, Woods, Algazi, Knight, & Näätänen, 1994; Giard, Perrin, Pernier, & Bouchet, 1990). On the other hand, the generators reported for LLR mainly include the Heschl’s gyrus in the primary auditory cortex (Huotilainen et al., 1998; Liégeois-Chauvel, Musolino, Badier, Marquis, & Chauvel, 1994; Pool, Finitzo, Hong, Rogers, & Pickett, 1989).

The latencies of N1 and P2 responses were observed to be differentially affected by ageing. When the latencies of these LLR responses of the older adults were compared with that obtained by Kumar and Jayaram (2005) for young adults using unprocessed /ḍa/ stimuli, it was observed that the latencies of N1 was similar. However, the latencies of P2 responses were prolonged when compared to that reported by Kumar and Jayaram for young adults.

With temporal resolution training, changes were observed in the latencies of LLR response i.e. N1 latencies showed a significant reduction after training using the ATRT programme all the three response acquisition sites. However, a similar change was not observed in the latencies P2 and in the amplitude of the N1-P2 complex. From these findings, it can be inferred that the ATRT programme was able to bring about changes in the cortical processing. However, it affected the regions responsible for N1 and P2 latencies differently.

Research by Michie, Bearpark, Crawford, and Glue (1990) and Michie, Solowij, Crawford, and Glue (1993) have shown that N1 and P2 are affected differentially by the attention paid towards stimuli. These studies have shown that P2 responses decrease when attention was paid towards the stimuli. However, in the current study such a change was not observed as P2 latencies did not change significantly with auditory temporal resolution training. Both before and after temporal resolution training, the recording was done while the adults watched a silent movie and they were asked to not pay attention to the auditory stimuli. Thus, it can be construed that their lack of attention towards the auditory stimuli could have resulted in no difference in P2 latency.

The change in the N1-P2 complex of the LLR responses observed in the present study is in contrast to the findings of Tremblay et al. (2001). They reported changes in the N1-P2 complex after training for VOT perception. With training, Tremblay et al. found changes in the amplitude of the N1-P2 complex but no change in the latencies of N1 and P2. However, in the current study only the latencies of N1 showed a decrease after training while no changes occurred in P2 latency and the amplitude of N1-P2 complex. The probable reason for this difference in finding could be the stimulus used for training and the age of the participants who were trained. Tremblay et al. used speech stimuli for training young adults in the age range of 21 to 31 years while in the current study nonverbal stimuli was used to train older adults in the age range of 55 to 75 years.

Hence, null hypothesis *3h, "Temporal resolution training has no significant effect on speech evoked cortical responses"* is rejected for latency of LLR and accepted for MMN and amplitude of LLR. The null hypothesis *4h, "temporal resolution training results in no significant difference on performance 4 weeks after cessation of training on Speech evoked cortical responses"* is accepted for both MMN and LLR.

From the overall findings of the study, it can be deduced that the changes observed in the responses of the participants after the ATRT programme serves as evidence for the presence of auditory plasticity in older adults. Plasticity related changes in older adults have been reported by numerous studies in the literature. These include changes in memory, cognitive functioning, auditory processing and speech in processing (Anderson, White-Schwoch, Choi, et al., 2013; Anderson, White-Schwoch, Parbery-Clark, et al., 2013; Mahncke et al., 2006; Morais et al., 2015).

Thus, from the findings of the study at hand it can be observed that the ATRT programme not only had a positive impact on the auditory process that was targeted at, but also on processes that were not aimed at during training. Transfer of learning took place from temporal resolution abilities to temporal patterning, binaural integration, and auditory separation/closure. In addition, the auditory memory span also showed improvements. The positive effect of the training was not only observed in the behavioural measures carried out, but also in one of the electrophysiological tests that was administered. This outcome augments the findings of Tremblay, Kraus, Carrell, and McGee (1997). They reported of ‘transfer of learning’ in young adults trained on discrimination of prevoiced labial stop to discrimination of prevoiced alveolar stop not present in their native language of English. Thus, it can be concluded that transfer of learning not only takes place in children and young adults, but also takes place in older adults.

The improvements seen in the current study in other auditory processes that were not tapped by the training programme can be attributed to an overlap of the cortical areas responsible for these auditory processes. This can be construed from the findings of Anton et al. (1996) who reported that the central sulcus was activated during hepatic discrimination of shape and finger movements. According to them, the overlap in the representations in the brain helps account for the plastic changes associated with learning. A similar overlap may also be present in the cortical areas representing auditory functions.

It can be construed from the findings of the current study that the ATRT programme was not only effective in helping the older adults overcome the difficulties in temporal resolution that was directly addressed but also difficulties in other auditory processes. The other auditory processes that showed improvement following the ATRT programme included temporal ordering, binaural integration, auditory separation / closure, and auditory memory. As these improvements in the behavioural tests were supported by physiological evidence of improvement, it is recommended that this programme be used to reduce the auditory processing difficulties in older individuals. The study also provides evidence for the presence of auditory plasticity in older individuals.

Chapter 6

SUMMARY AND CONCLUSIONS

Auditory processing abilities have been reported to decline with advance in age (Dubno et al., 1984; Gelfand et al., 1985; Gordon-Salant, 1986; Pedersen et al., 1991; Prosser et al., 1991; Strouse et al., 1998). Decline in *auditory temporal processing* has been noted to occur in several studies (Bertoli et al., 2002; Fink et al., 2005; Fitzgibbons et al., 2006; He et al., 1999; John et al., 2012; Pichora-Fuller et al., 2006; Roberts & Lister, 2004; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002; Trainor & Trehub, 1989; Vaidyanath & Yathiraj, 2015). Besides temporal deficits, older adults have been found to have problems in *binaural integration* (Cox et al., 2008; Jerger et al., 1995; Jerger et al., 1994; Roup et al., 2006), *auditory separation / closure* (Dubno et al., 1984; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008), and *binaural interaction* (Pichora-Fuller & Schneider, 1991; Strouse et al., 1998). Additionally deficits in cognitive functions like auditory memory have also been reported in older adults (Craik & Byrd, 1982; Grady & Craik, 2000; Old & Naveh-Benjamin, 2008; Salthouse, 1996a, 1996b). From the literature, it was evident that though numerous studies have confirmed the presence of auditory processing difficulties in older adults, research focussing on rehabilitation of these individuals with auditory processing deficits is sparse.

The current study was carried out with the aim to determine the efficacy of ‘Auditory Temporal Resolution Training programme (ATRT)’ in older adults with near normal hearing. This aim was established by studying the effect of the training programme on auditory processing (temporal resolution, temporal patterning, binaural integration, and auditory separation/closure), voicing discrimination, auditory memory and sequencing as well as electrophysiological responses. To address this aim, the performance of older adults before and after ATRT was compared on the tests of temporal processing, binaural integration, auditory separation / closure, voicing discrimination, as well as auditory memory and sequencing. Additionally, the older adults were evaluated using cortical potentials (MMN & LLR). To evaluate temporal processing, the participants were evaluated using Gap-In-noise test (GIN; Musiek et al., 2005), Gap detection test (GDT; Shivaprakash, 2003) and Duration pattern test (DPT; Musiek et al., 1990) Binaural integration was examined using Dichotic CV test (DCV; Yathiraj, 1999) and, auditory memory and sequencing using Kannada auditory memory and sequencing test, (KAMST; Yathiraj & Vijayalakshmi, 2006). Auditory separation / closure abilities was assessed using Speech-perception-in-noise test in Kannada (SPIN-K), and Voicing discrimination was tested using voicing discrimination word test in Kannada (VDWT), both developed as a part of the current study.

The ATRT programme, developed as part of the present study, consisted of four different stimuli types (broadband noise, 500 Hz NBN, 1000 Hz NBN & 2000 Hz NBN) and four levels having increasing complexity. The training for all participants commenced at level I and progressed to level IV. The training was terminated when the participant maintained a score of at least 80% for 3 successive training sessions at level IV. The number of training sessions administered for each participant varied from 7 sessions to 13 sessions.

A total of 49 participants in the age range of 55 to 75 years were initially evaluated. They were divided into two age groups with 39 individuals aged 55 to 64;11

years and 10 individuals aged 65 to 74;11 years. Out of the 49 participants, 20 older adults with deficits in temporal processing (temporal resolution & patterning) were trained using the ATRT programme.

To study the effectiveness of the ATRT programme, the participants were evaluated twice prior to the training (pre-training evaluation-1 & pre-training evaluation-2) and twice following the training (post-training evaluation-1 & post-training evaluation-2). A minimum gap of two weeks was maintained between the two pre-training evaluations and a gap of four weeks was maintained between the two post-training evaluations. All the behavioural tests of auditory processing (GIN, GDT, DPT, DCV, & SPIN-K), voicing discrimination as well as auditory memory and sequencing were administered in each of these pre-training and post-training evaluations. The electrophysiological responses (MMN & LLR) were obtained only in pre-training evaluation-2, post-training evaluations-1 and 2.

The data collected were analysed to obtain information about the effect of the two age groups (55 to 64;11 & 65 to 74;11 years), effect of ear / scoring procedure as well as effect of the training. This was obtained using Mann-Whitney test, Friedman test and Wilcoxon signed rank test for the data that did not follow a normal distribution and repeated measure ANOVA for the data that were normally distributed. Additionally, a comparison of the performance of the older adults in relation to available norms of young adults was carried out.

The major findings of the study are as follows:

- *Age groups:* Prior to the comparison of the pre-training and the post-training evaluations, the performance to the two age groups (55 to 64;11 and 65 to 74;11 years) were compared. No significant difference was found between the two groups, indicating that they performed similarly on the tests of auditory processing, voicing discrimination as well as auditory memory and sequencing. It also indicated that with advance in age further deterioration in auditory processing abilities was not present.

- *Pre-training performance:* The comparison of the two pre-training evaluations indicated that there was no significant difference in performance. From this it was construed that in the absence of training the performance of the older adults was not influenced by any external variables. This also indicated that the test-retest reliability of the behavioural tests were high.

- *Ear difference:* The presence of ear difference was evaluated on all the tests that were administered monaurally (GIN, GDT, DPT, SPIN-K & VDWT). A significant difference between the performances of the two ears was not observed in any of these tests.

- *Influence of ATRT on temporal resolution:* The performance of the older adults on tests of temporal resolution was found to be poorer than the norms for young adults on GIN given by Aravindkumar et al. (2012) and GDT given by Shivaprakash (2003). Following temporal resolution training, significant improvement was seen in the performance on both the tests of temporal resolution (GIN & GDT) that were administered. This was observed in the form of reduction in the gap detection thresholds and a reduction in the number of individuals who failed the two tests. This indicated that the participants were able to detect smaller duration gaps after training.

- *Influence of ATRT on temporal ordering:* Temporal ordering assessed using DPT showed enhanced performance after the ATRT programme. A significant improvement in the DPT scores as well as an increase in the number of individuals who obtained scores similar to the norms for young adults given by Gauri (2003) was observed. Thus, temporal resolution training improved temporal ordering abilities as well.

- *Influence of ATRT on binaural integration: Significant* improvement in the single correct scores of the right and left ears as well as double correct scores of the DCV were observed after temporal resolution training. This showed the positive impact of the training on binaural integration. However, several of the participants continued to obtain poorer scores compared to that of young adults reported by Prachi (2000).

- *Influence of ATRT on auditory separation / closure:* Auditory separation / closure abilities, assessed using SPIN-K, were also found to be positively affected in the older adults after training. The number of individuals with scores below the norms of Kalikow et al. (1977) reduced following temporal resolution training.

- *Influence of ATRT on voicing discrimination:* Unlike the improvements observed in other auditory processes following temporal resolution training, voicing discrimination abilities assessed using VDWT, did not show any change. The presence of a ceiling effect on the scores of the test prior to the training was considered as a reason for the absence of an improvement. The use of a more difficult test, with less redundant cues, is recommended to avoid such a ceiling effect.

- *Influence of ATRT on auditory memory and sequencing span:* The auditory memory span and the sequencing span obtained using KAMST were poorer than the norms given by Vaidyanath and Yathiraj (2014a) before the administration of the ATRT programme. Following training, the auditory memory span showed significant improvements, but not the auditory sequencing span. This indicated that ATRT had a positive impact on auditory memory span.

- *Influence of ATRT on cortical responses:* In addition to the changes observed in the behavioural tests, electrophysiological evidence in the form of reduction in the latencies of N1 of LLR following temporal resolution training was observed. However, a similar change in latency of P1 and amplitude of N1-P2 was not observed. Additionally, changes in MMN were also not observed following temporal resolution training. This difference in the responses of MMN and LLR were attributed to the differences in the generators of the two cortical responses.

- *Variability in performance:* In all the tests, variability in the scores were seen prior to administration of ATRT training as well as in the improvement observed following training. This showed that the initial difficulties of the participants varied, as did the amount of improvement.

- *Maintenance of training:* The improvements observed in temporal resolution, binaural integration, auditory separation / closure and auditory memory span were maintained 4 weeks post cessation of temporal resolution training.

- *Generalization of temporal resolution training to other processes:* From the results of the study, it was concluded that the ATRT programme was effective in training older adults with auditory processing deficits. This was not only effective in improving the temporal resolution abilities that it directly tapped but also other auditory processes including temporal ordering, binaural integration, auditory separation / closure, and higher cognitive process (auditory memory).

The positive changes observed in the responses of the older adults following ATRT programme provides evidence for the presence of auditory plasticity in these individuals. The results also indicate that transfer of learning from temporal resolution abilities to temporal patterning, binaural integration, and auditory separation / closure. Hence, it is recommended that ATRT programme be used in older adults to overcome the effects of ageing on auditory processing abilities.

Implications of the study:

The implications of the study are as follows:

- The study adds information to the existing corpus of information regarding the auditory processes that are deviant in older adults.
- The study proves that direct remediation activities are useful not only in children but also in older adults.
- Specific auditory training brings about change not only in the process that is targeted but also in other processes.
- The reduction in LLR latencies indicates that the developed training material does bring about changes in cortical responses.
- The findings of the study prove that auditory training does result in auditory plasticity even in older adults.
- The developed training material that has been proven to be useful will be helpful in rehabilitating adults who have temporal processing problems. It will also be helpful for other auditory processing / higher cognitive problems such as auditory separation, auditory integration, and auditory memory problems.

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Chapter 5

DISCUSSION

The results of the current study that aimed to determine the efficacy of auditory temporal resolution training (ATRT) in older adults with near normal hearing, are discussed for different central auditory processes (temporal resolution, temporal patterning, binaural integration, & auditory separation / closure), voicing discrimination as well as auditory memory and sequencing. Initially, the difference in performance in the two age groups (55 to 64;11 & 65 to 74;11 years) are discussed. Prior to discussing the effect of the training programme, the difference in scores of the left and right ears for each of the tests as well as the performance of the older adults in relation to available norms are discussed. The effect of ATRT are discussed with regards to the performance of the participants on the Gap-In-Noise test (GIN), Gap Detection test (GDT), Duration Pattern Test (DPT), Dichotic CV test (DCV), Speech-Perception-in-Noise test in Kannada (SPIN-K), Kannada Auditory memory and sequencing test (KAMST), and Voicing discrimination word test in Kannada (VDWT).

5.1 Effect of age on test performance (auditory processing, voicing discrimination, & auditory memory)

The comparison of the two age groups in the present study revealed no significant difference between them. No deterioration with advance in age was observed for the performance on the auditory processes assessed (temporal processing, binaural integration, and auditory separation/closure), voicing discrimination as well as auditory memory and sequencing. This is in contrast to the findings of Kumar and Sangamanatha

(2011) who reported that difficulty in certain temporal processing (gap detection, duration discrimination & modulation detection thresholds) was noticeable in individuals above the age of 40 years while deficits on duration pattern scores was noticed only after the age of 60 years. The difference in the findings of the two studies could be due to the methodology used. In the current study, tests of temporal processing were administered monaurally whereas Kumar and Sangamanatha used binaural assessment. It has been noted that performance on monaural presentation results in less deterioration comparison to binaural processing (Szymaszek et al., 2006). Based on the findings of the current study, null hypothesis 1, *"There is no significant difference between the performance of the two age groups on auditory processes [temporal resolution (2 tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing"*, is accepted.

5.2 Comparison of performance on behavioural tests in pre-training evaluation-1 and pre-training evaluation-2

The performance on the tests of auditory processing (GIN, GDT, DPT, DCV, SPIN-K), voicing discrimination and auditory memory did not change when no intervention was provided. This is evident from the comparison of the two pre-training evaluations (pre-training evaluation-1 & pre-training evaluation-2). This occurred immaterial of the test that was administered. Thus, it can be construed that no external variables influenced the performance of the individuals and that their scores on the tests remained stable when evaluated over a period of time when no intervention is provided. These results also established that the test-retest reliability of all the tests that were administered in both the evaluations were high. Hence, null Hypothesis 2, *"There is no* *significant difference in performance on auditory processes [temporal resolution (2 tests), temporal patterning, auditory integration, and auditory separation / closure], voicing discrimination as well as auditory memory and sequencing without intervention/training"*, is accepted.

5.3 Performance of the participants on auditory processing, voicing discrimination, and auditory memory

The performance of the older adults in relation to available norms is discussed to shed light on the difference in abilities between this age group and young adults. In addition, comparison of ears of the participants is discussed for each of the tests where ear specific information was obtained. Further, the ATRT programme was found to have varying effects on the behavioural tests and the electrophysiological test that were studied. The effect was observed to depend whether the tests directly evaluated the auditory process for which training was provided (GIN & GDT) or not (Duration Pattern, Speech-Perception-in-Noise, Voicing discrimination word test in Kannada, Auditory memory and sequencing, & LLR). The above are discussed for each of the tests administered.

5.3.1 Temporal resolution performance of older adults:

Temporal resolution was studied using two tests (GIN & GDT). The performance of the older adults in relation to the norms established for young adults, the differences in the performance across the two ears of the older adults and the effect of ATRT training on the gap detection thresholds obtained using the two tests are discussed below.

Performance in relation to norms of young adults: The performance of the older adults prior to training was poorer than the published norms for younger adults on the two tests of temporal resolution, GIN (Aravindkumar et al., 2012) and GDT (Shivaprakash, 2003). This indicates the presence of temporal resolution deficits in these individuals in spite of normal / near normal hearing sensitivity.

Similar results were also reported by researchers using gaps embedded in noise stimuli (He et al., 1999; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Vaidyanath & Yathiraj, 2015). This age related deterioration in temporal resolution abilities was also found using mismatch negativity (MMN) by Bertoli et al. (2002). However, the findings are in contrast to that of Moore et al. (1992) and Roberts and Lister (2004) who reported that gap detection thresholds of some older adults were similar to that of younger adults using pure-tones and white noise respectively.

From the findings of the present study and those reported in the literature on gap detection thresholds of older adults, it can be inferred that most individuals in this age group do have difficulties in gap detection. This occurs despite normal / near normal hearing sensitivity. This highlights the need to provide training to counter the adverse effects of such a problem.

Performance across the ears: The gap detection thresholds of the right and the left ear, obtained using GIN and GDT, were found to not differ significantly. This is in congruence with the findings of Shivaprakash (2003) in young adults using GDT and Aravindkumar et al. (2012) using GIN. This is also similar to the reports of other researchers (John et al., 2012; Schneider et al., 1994) who did not report of any significant difference between the performances of the two ears in older adults. The absence of an ear difference can be ascribed to nonverbal stimuli (noise & tones) being processed bilaterally in the auditory cortex, as reported by Binder et al. (2000) and Mirz et al. (1999). The stimulation of the two hemispheres in a similar manner could have led to the two ears performing in a similar way, resulting in no significant difference between them.

The above findings are in contrast to those reporting of right ear advantage in gap detection especially for broadband noise (Sininger & de Bode, 2008; Sulakhe, Elias, & Lejbak, 2003). According to Sulakhe et al. (2003) and Sininger and de Bode (2008), a right ear advantage in gap detection was observed as the left hemisphere has been reported to better code temporal- related information.

Thus, it can be observed that there is no consensus in the literature regarding ear symmetry for gap detection. However, the majority of studies indicate that gap detection is similar across the two ears. The findings of the present study are similar to the majority of studies that report of no ear difference.

Effect of ATRT training: The findings of the current study indicated that temporal resolution training had a significant positive effect on temporal resolution abilities of the older adults, measured using GIN and GDT. This improvement can be attributed to the effect of the ATRT programme and not due to any co-existing variables. This can be substantiated as without any intervention, no change in performance was observed during the two pre-training evaluations. The intervention could have enabled the older adults to attend better to short-duration gaps that they probably tended to ignore with advance in age. The ATRT programme probably stimulated their superior temporal gyrus near the primary auditory cortex area, which has been reported to be the areas responsible for detection of small duration gaps in auditory stimuli by Heinrich, Alain, and Schneider (2004), thereby brining about improvement in the gap detection thresholds.

The observed changes with temporal resolution training can also be attributed to better abilities to overcome the effect of temporal masking. It has been reported that older adults required longer gap between masker and signal to detect the presence of a signal (Elliott, 1962; Gehr & Sommers, 1999; Gifford et al., 2007; Newman & Spitzerb, 1983; Walton et al., 1999). In a gap detection task the preceding marker is likely to mask the gap succeeding it, thereby enabling older adults to perceive only longer gaps. With temporal resolution training, this masking effect may have reduced leading to better gap detection thresholds.

Additionally, in spite of a difference in the pattern of gaps used for the ATRT programme and GIN, the gap detection thresholds were found to improve in GIN. It can thus be inferred that training using gaps that occur at regular intervals, similar to that present in GDT, can result in generalised learning of random gaps that occurs in GIN.

Further, in the present study it was found that the temporal resolution abilities continued to be significantly better than the pre-training evaluations. This improvement was seen despite gap detection thresholds obtained using GDT showing a significant deterioration one month after the cessation of training. However, with GIN such a deterioration did not occur, although it is considered a more difficult test compared to GDT by Vaidyanath and Yathiraj (2015). A possible reason for the significant reduction in scores for GDT and not for GIN could be due to exposure to random gaps present in speech. This could have helped in the maintenance of random gap thresholds of GIN. To prevent such deterioration, instead of abruptly stopping training, it is recommended that training should be continued with the frequency of training sessions and the duration of the sessions being gradually reduced.

It can be observed from Figure 4.1 (a, b) and Figure 4.2 (a, b) that with temporal resolution training the gap detection thresholds improved and were found to be similar to that of young adults (depicted by the shaded area). In addition, from the figures it can be observed that although the majority of participants displayed improvement in gap detection thresholds, the amount of change varied from one participant to another. Thus, the improvement in the gap detection thresholds resulted in a reduction in the number of older individuals failing the two tests of temporal resolution. This number reduced from 17 to 5 in GIN and 16 to 3 in GDT. Among those who continued to fail the tests, two failed both tests (participant no. 12 and 20). These participants had larger gap detection thresholds compared to all the other participants on GIN. While they did show improvement in gap detection thresholds, this improvement was not sufficient to reach the norms for young adults.

The results bring to light that temporal resolution training enabled the majority of the participants to perform similar to young adults, thus making it possible for them to pass the temporal resolution tests that they failed before the training. Since all the participants did not pass the two temporal resolution tests despite showing some benefit, it indicates that some of them probably required longer duration of training to attain scores similar to young adults.

In addition to the variability in the improvement seen in the gap detection thresholds, variability was also observed in the number of training sessions required by the older adults to reach the criterion for termination of ATRT training. The number of training sessions ranged from 7 sessions to a maximum of 13 sessions. The six participants who did not reach the norms of the two tests also required above 9 training sessions, with most of them requiring more than 11 sessions.

Therefore, null hypotheses, *3a "Temporal resolution training has no significant effect on performance in tests of temporal resolution (GIN & GDT)"* is rejected. On the other hand, null hypothesis, *4a "Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in tests of temporal resolution (GIN & GDT)"* is accepted.

5.3.2 Temporal patterning performance of older adults:

The effect of age on the temporal patterning abilities and the comparison of the performance across the two ears of the participants are discussed below. Additionally, the effect of ATRT training on scores on temporal patterning, assessed using DPT, is also discussed.

Performance in relation to norms of young adults: Temporal patterning abilities of the older adults in the present study before training were found to be poorer than that reported for younger adults by Gauri (2003). This can be deduced from the poorer scores of the older individuals in comparison to the norms for younger adults obtained by Gauri (2003), depicted in Figure 4.3. The poorer performance of the older adults compared to young adults on tests of temporal patterning is in line with studies reported in literature

(Fink et al., 2005; Fitzgibbons et al., 2006; Newman & Spitzerb, 1983; Szymaszek et al., 2006; Trainor & Trehub, 1989). The reasons reported for the poor temporal patterning performance of the older adults are uncertainty in the perception of the stimuli (Trainor & Trehub, 1989) and slowing of temporal information processing with ageing (Fink et al., 2005; Kumar & Sangamanatha, 2011; Szymaszek et al., 2006). However, these findings are in contrast to that reported by Fitzgibbons and Gordon-Salant (1998) who failed to obtain any significant effect of age. This probably occurred as they used a temporal order discrimination task rather than temporal order identification. According to them, the lesser complexity of the discrimination task used could have led to the observed results.

Performance across ears: The temporal patterning abilities of the two ears did not differ significantly in the participants of the present study. A similar result was also reported by Gauri (2003) and Musiek, Baran, et al. (1990) for young adults. This indicates that the deterioration in the temporal patterning abilities that occurs with ageing is similar across the two ears. These results were similar to that obtained for temporal resolution where a significant difference between the performances of the two ears was not found. As mentioned earlier, nonverbal stimuli are processed in both the hemispheres of the brain. With ageing, both hemispheres were probably affected in a similar manner, resulting in similar deficits in the ability to processes temporal order of the signals. This would have resulted in the lack of significant difference between the two ears.

Effect of ATRT training: The temporal patterning abilities showed significant improvement after the administration of ATRT programme. This improvement is evident from the mean/median scores of the duration pattern test (Table 4.7). Further, following training there was a marginal increase in the number of older individuals who achieved scores similar to the norms of young adults given by Gauri (2003). However, the extent to which the temporal patterning scores increased following training varied from one participant to another. A few of the participants show no change in the scores, as evident from the overlapping points in Figure 4.3 (a, b). The lack of change in performance in these participants (participants 8, 10, 11, 13, 14, 15, 17 & 19) can be attributed to a ceiling effect since their pre-training performance was already approximated the maximum attainable score. Hence, it can be inferred that those participants who had temporal pattern processing difficulties did benefit from the training programme and showed marked improvement subsequent to it (participants 1, 2, 3, 6, 9, 12, 18 & 20).

The variability in the performance of the participants was also evident depending on whether the pre- and post-training evaluations were compared for the 10 participants who partook throughout the study or whether the data of all 20 participants were evaluated. While a significant difference was evident between pre-training evaluation-1 and post-training evaluation-1 with the 20 participants, it was absent when the analysis was done with the 10 participants. In addition, there was no significant improvement between pre-training evaluation-1 and post-training evaluation-2. A probable reason for this discrepancy in findings could be the variability in performance of the participants across the evaluations. From the raw data, it was observed that the participants who showed an improvement in the duration pattern test did not participate in the post-training evaluation-2. Seven (participants 1, 5, 7, 9, 16, 19, & 20) out of the 10 participants who were evaluated in post-training evaluation-2 were those who obtained a ceiling effect, i.e. high scores in pre-therapy evaluation-1 (Figure 4.3 a, b). This could have led to no significant difference between the pre-training and post-training evaluations. However, from the performance of the 20 participants soon after the training, it can be inferred that the ATRT programme does have a positive effect on pattern perception. Had those who had no ceiling effect been tested during evaluation-2, a positive impact of training would have been seen in this post-training evaluation also.

The improvement in temporal patterning performance following temporal resolution training has support from the findings of Morais et al. (2015). They observed improvements in temporal patterning abilities in older adults in addition to improvements in auditory closure, dichotic listening, and temporal resolution following 'acoustically controlled auditory training'. Thus, it can be inferred that training in one process can result in improvement in another related process.

Thus, null hypothesis *3b "Temporal resolution training has no significant effect on performance in a test of temporal ordering (Duration Pattern Test)"* is rejected and null hypothesis *4b "Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in a test of temporal ordering"* is accepted.

5.3.3 Binaural integration performance of older adults:

Binaural integration abilities were found to be affected in the older adults evaluated in the current study. This difficulty was found to be positively influenced by the administration of the temporal resolution training. These findings are discussed below.

Performance in relation to norms of young adults: The Dichotic CV scores (right single correct, left single correct, & double correct scores) of the older adults were found to be poorer than that reported by Prachi (2000) for young adults. Deterioration in the dichotic speech perception with age has also been reported for dichotic sentences (Jerger et al., 1995; Jerger et al., 1994), and NU-6 monosyllabic words presented dichotically (Roup et al., 2006). This deterioration in dichotic speech perception is reported to be due decline of cognitive factors like memory, inefficient inter-hemispheric transfer of information in the corpus-callosum (Jerger et al., 1994) and progressive atrophy or progressive loss of myelination of corpus callosal fibres (Jerger et al., 1995).

Further, in the current study, the right ear advantage obtained by the older adults was more than that reported by Prachi (2000) for younger adults. While the older adults in the present study had an advantage of 2.85, that reported for younger adults by Prachi was 1.64. On observation of the raw scores of the older adults, it was noted that this increased right ear advantage was on account of a decrease in the scores of the left ear, with a lesser decrease in the right ear scores. This increased right ear advantage due to a decrease in left ear scores was also reported by Jerger et al. (1994) and Jerger et al. (1995). This decrease in the left ear scores has been considered to occur due to the effect of ageing on the pathway carrying information from the left ear and the inter-hemispheric transfer of information (Jerger et al., 1994). This finding is in contrast to the findings of Gelfand et al. (1980) who reported similar right ear advantages between young and older adult groups for dichotic CV stimuli. Gelfand et al. (1980) suggested that the auditory mechanism responsible for the right ear advantage was not affected by age leading to similar right ear advantages in the two groups.

Effect of ATRT training: Like the other tests, the binaural integration abilities assessed using the Dichotic CV test scores showed improvement after the ATRT programme. This is evident from the scores in Table 4.7. Enhancements in single correct scores of the right and left ears as well as the double correct scores were observed. Despite these improvements, in some participants the scores did not reach the norms for young adults given by Prachi (2000). This difference in performance is noticeable in Figure 4.4 (a, b, c). Additionally, the amount of improvement in scores was variable across the participants, similar to that seen in the other tests that were administered. Further, the improvement in the scores observed immediately after the cessation of training, was maintained 4 weeks after the cessation of training. This is shown by the absence of a significant difference between the scores in the two post-training evaluations.

From the improved performance in the Dichotic CV test following the ATRT programme, it can be surmised that training in auditory temporal resolution does have a positive impact on binaural integration. This probably occurred since the training led to an improvement in perception of auditory temporal cues important for consonant recognition in these older adults. The other possible reason for this could be the increased alertness of the older adults to the stimuli presented following the training.

The improvement seen in the binaural integration abilities of older adults following ATRT training is in consensus with the findings of Morais et al. (2015). They reported that their older adults who were trained using ‘acoustically controlled auditory training’ demonstrated improvement in dichotic listening, in addition to improvement in auditory closure, temporal ordering and temporal resolution.

From the above finding, it can be concluded that null hypothesis *3c, "Temporal resolution training has no significant effect on performance in test of Binaural integration (Dichotic CV test)"* is rejected. On the other hand, null hypothesis *4c, "Temporal resolution training has no significant difference on performance 4 weeks after cessation of training in a test of binaural integration (Dichotic CV test)"* is accepted.

5.3.4 Auditory separation/closure performance of older adults

The effect of age, the difference in the performance of the two ears of the older adults, and the effect of ATRT training on auditory separation / closure abilities were studies in the current study. The auditory separation / closure abilities of the participant are discussed based on their performance on SPIN-K.

Performance in relation to norms of young adults: The mean and median scores of the older adults before the training on the Speech-Perception-in-Noise test in Kannada (SPIN-K) were considerably lower than the scores reported by Kalikow et al. (1977) for young adults. This can be observed from Figure 4.5 (a, b) that indicates that the scores of the older adults in pre-training evaluation-1 were below the norms of younger adults, represented by the shaded area.

The poorer performance of the older adults in comparison to younger adults is supported by studies reported literature (Dubno et al., 1984; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008; Wong et al., 2010). Such poorer performance has been reported in studies using different speech materials (Dubno et al., 1984; Frisina & Frisina, 1997; Pichora-Fuller et al., 1995), background noise (Prosser et al., 1991; Russo & Pichora-Fuller, 2008), and signal-to-noise ratios (Gelfand et al., 1986). The reasons reported by these authors for the poor performance include auditory dysfunction associated with the cochlear mechanisms, deterioration in short-term memory (Dubno et al., 1984; Pichora-Fuller et al., 1995) and poor abilities to extract features required for speech perception (Dubno et al., 1984).

The poorer speech perception in the presence of noise observed in these older adults could have been due to poor functioning of the medial olivocochlear system, as noted by Mukari and Mamat (2008). They reported a correlation between the medial olivocochlear system functioning and speech recognition in presence of noise. They also reported that in older adults the contralateral suppression of distortion product otoacoustic emissions was significantly lower, especially in the high frequencies compared to the younger adults considered in their study.

Performance across ears: The performance of the two ears on SPIN-K was found not to be significantly different. This lack of significant difference indicates that the processing of speech in the presence of noise was equally affected in the two ears. Wong, Uppunda, Parrish, and Dhar (2008) found bilateral activation of superior temporal gyrus while individuals listened to speech presented in presence of noise, indicating that both hemispheres are responsible for speech perception in noise. The findings of the current study indicate that with ageing these cortical areas are symmetrically affected, resulting in similar performance across the two ears. A similar performance of the two ears has also been reported by Mukari and Mamat (2008).

Effect of ATRT training: The scores on SPIN-K, after training using ATRT programme was found to be significantly better in comparison to the scores before training. In addition to the SPIN-K scores, the positive effect of the ATRT programme on perception of speech in the presence of noise was also evident from the subjective reports of four of the participants. These participants reported of decreased difficulty while listening to SPIN-K after the training, in comparison to their difficulty prior to the training.

The ATRT programme not only helped improve perception of speech in the presence of noise immediately after the training, but also enabled maintenance of this improvement 4 weeks after the cessation of the training. Although a slight deterioration was observed in the scores 4 weeks post-training, though not significant, the scores obtained in post-training evaluation-2 remained significantly higher compared that obtained in pre-training evaluation-1.

After training, the scores of some of the participants (N = 9) improved to reach the scores of young adults. However, in some the participants who showed improvement in performance (N = 6), the scores continued to be below the normative value range. From this, it can be construed that the effect of ATRT programme was variable, with some participants improving more in comparison to others. The variability in the improvement in the scores seen after the temporal resolution training could also be due to the variations in the amount of difficulty experienced by the older adults. From Figure 4.5 (a, b) it can be noted that the amount of improvement shown by the individual after temporal resolution training was not dependent on their initial difficulty. The improvement was observed not only in those individuals who had relatively better SPIN-K scores but also in individuals with poorer SPIN-K scores.

The improvement seen in SPIN-K scores with training in temporal resolution is in consensus with studies reported in literature that indicated that a relation exists between gap detection thresholds and speech perception in presence of noise (Phillips et al., 2000; Snell & Frisina, 2000; Snell et al., 2002). According to Phillips et al. (2000), reduced temporal resolution abilities contributed to difficulties in syllable recognition in the presence of noise. Thus, it can be inferred that an improvement in the temporal resolution ability following training can lead to improvement in speech recognition in the presence of noise. This probably occurred since an improvement in temporal resolution ability would have enabled the older adults to utilise short duration cues available in speech, thereby improving the intelligibility of the speech signal presented in the presence of background babble. This reasoning can be corroborated with the findings of Phillips et al. (1997) who reported that across-channel gap detection (gap detection with the leading and training markers having different frequencies) resembled perception of VOT cues in speech. Although the current study utilised gap detection training with leading and training markers having similar frequencies, it can be inferred to have a similar effect as the stimuli used by Phillips et al. This is based on the findings of Heinrich et al. (2004) who found that at the auditory cortical level, significant differences between with-in and across-channel gap detection did not occur when measured using MMN. Thus, it can be construed that ATRT training, which resulted in an improvement in temporal resolution abilities, could have also helped in improving the perception of these VOT cues in speech that in turn could have led to an improvement in SPIN-K scores.

Hence, null hypothesis 3d, *"Temporal resolution training has no significant effect on performance in a test of auditory separation*/closure (Speech-Perception-in-Noise test in Kannada)" is rejected. With reference to the maintenance of the effect of training, null hypothesis 4d *"Temporal resolution training results has no significant difference on performance 4 weeks after cessation of training in a test of auditory separation/closure (Speech-Perception-in-Noise test in Kannada)"* is accepted.

5.3.5 Voicing discrimination performance of older adults

The outcome of the analyses regarding the performance of voicing discrimination abilities of the two ears of the participants are discussed below. Additionally, the influence of ATRT training on the performance in the 'Voicing discrimination word test in Kannada', developed in the current study, is also discussed.

Performance across ears: The performance of the two ears of the participants of the current study was observed to be identical on the 'Voicing discrimination word test in Kannada'. This symmetry in performance in the two ears was evident without as well as with training. The symmetry was as expected since monaural speech discrimination scores are known to result in similar performance in the left as well as right ear. The study demonstrates that such symmetry that is typically noted in young adults is maintained with ageing.

Effect of ATRT training: Voicing discrimination abilities assessed using the 'Voicing discrimination word test' did not show any changes after temporal resolution training. The performance across the three evaluations did not show any significant difference. The lack of improvement in the scores of the 'Voicing discrimination word test in Kannada' is also indicated in Figure 4.7 (a, b). It can be observed from the figure that the performance of most of the older adults approximated the maximum possible score on the test with marginal change in these scores across evaluations. Due a ceiling effect on the scores prior to the training, there was not much scope to record any improvement.

The findings indicate that the task of discriminating voicing differences at word initial and medial position was not difficult for the older adults. This could have occurred since they may have utilised redundant cues present within the consonants as well as coarticulated cues. It is possible that on a more taxing test with multiple redundant cues being removed, the impact of training will be seen on voicing perception. It needs to be studies if making the task more difficult by evaluating word discrimination testing in the presence of noise, testing word identification or phoneme identification instead of discrimination, can identify voicing difficulty more effectively, prior to training.

Therefore, null hypothesis *3e, "Temporal resolution training has no significant effect on performance in the 'Voicing discrimination word test in Kannada'"* is accepted. The null hypothesis *4e, "Temporal resolution training results in no significant difference on performance 4 weeks after cessation of training in voicing discrimination word test in Kannada"* is also accepted.

5.3.6 Auditory memory and sequencing performance of older adults

The effects of ATRT training on auditory memory and sequencing abilities are discussed below. Prior to that, the effect of age on the auditory memory and sequencing abilities are discussed.

Performance in relation to norms of young adults: The auditory memory and sequencing abilities of the older adults were poorer than the norms reported by Yathiraj and Vijayalakshmi (2006). This can be inferred from the scores in Table 4.9 and Figure 4.6 (a, b). The reduced memory abilities in older adults observed in the current study are supported in literature (Grady & Craik, 2000; Old & Naveh-Benjamin, 2008). Some of the reasons noted for the reduced memory abilities in older adults include the reduction in the processing speed (Salthouse, 1996a, 1996b), reduced attentional resources (Craik & Byrd, 1982), and reduced working memory (Salthouse, Mitchell, Skovronek, & Babcock, 1989).

Effect of ATRT training: From the Table 4.9 and Figure 4.6 (a) it is evident that the auditory memory span changed after temporal resolution training The improvement observed in auditory memory span is also indicated by the presence of a significant difference between the pre-training evaluation-1 and post-training evaluation-2. About 50% of the individuals showed some changes in auditory memory span after undergoing the ATRT programme, with the other 50% showing no change in performance. However, in none of the participants did the auditory sequencing span show any change after training.

The improved auditory memory span after ATRT programme was maintained four weeks after the cessation of training. This is indicated by the absence of significant difference in performance in the two post-training evaluations. The improvement in auditory memory span after training probably occurred as the participants learnt to attend to stimuli more intently. Further, it can be inferred that the memory load of some of the training activities, especially the three and four-sequencing stimulus-sets could have helped in improving their memory skills. The participants would have not only have had to be vigilant in detecting gaps embedded in noise, but recall from memory which of the noise bursts contained the gap. This could have had a positive effect on their memory skills.

The generalization of the improvements following temporal based training on to auditory memory is also reported by Maggu and Yathiraj (2011b). They observed that temporal patterning training not only improved the temporal patterning abilities of the children who were trained but also improved the auditory memory and sequencing abilities of these children.

Thus, it can be inferred that null hypothesis *3f, "Temporal resolution training has no significant effect on performance in a test of auditory memory and sequencing (Kannada auditory memory and sequencing test)"* is accepted for the auditory memory span, but is rejected for the auditory sequencing span. Further, null hypothesis *4f, "Temporal resolution training results has no significant difference on performance 4 weeks after cessation of training in a test of auditory memory and sequencing (Kannada auditory memory and sequencing test)" is accepted.*

5.3.7 Phoneme error pattern in the presence of noise in older adults

The phoneme errors of the participants, prior to and after ATRT training, was analysed from their SPIN-K responses. The same are discussed below.

Effect of ATRT training: A number of phoneme errors, when calculated as percentage of errors after eliminating the 'no responses', were observed in the presence of noise prior to the temporal resolution training. Prior to training, the maximum percentage of errors occurred for manner of articulation (77.7%) followed by place of articulation (53.38%) errors and voicing errors (46.62%), in isolation and in combination. The general phoneme error pattern is similar to that noted by Gelfand et al. (1986) who studied phoneme errors of older adults using a nonsense syllable test. They reported a decrease in the information transfer for manner of articulation and place of articulation with age. This decrease was noted more for stop manner of articulation followed by place of articulation information and frication feature information. This deficit was ascribed to deterioration in the use of durational cues with age, which were considered important for the perception of stops and fricative features. Additionally, this decrease was noted to be more in the presence of noise when compared to quiet. According to Gelfand et al., the decrease in the ability of the older adults to utilise perceptual cues available to them was one reason for the errors observed. The effect of age on certain cues that were least robust in the younger adults for perception of speech especially in presence of noise was another reason suggested by them.

The findings of the current study and that of Gelfand et al. (1986) are unlike the typical errors noted in individuals with peripheral hearing loss where place errors are noted to higher than manner and voicing (Bilger & Wang, 1976; Gordon-Salant, 1987;

Revoile & Pickett, 1982; Walden & Montgomery, 1975). The probable reasons for this difference in the order of speech feature difficulties could be due to the acoustic cues that are utilised by the two groups. While those with peripheral hearing loss have been noted to have more problems in spectral resolution, those in the current study had more temporal perception problems. It is known that spectral cues are important for the perception of places cues (Alwan, Jiang, & Chen, 2011; Bilger & Wang, 1976; Blumstein, & Stevens, 1979; Gordon-Salant, 1987; Kewley-Port, Pisoni, & Studdert-Kennedy, 1983; Revoile & Pickett, 1982; Stevens & Blumstein, 1978; Walden & Montgomery, 1975) and temporal cues are important for the perception of manner cues (Alwan, Jiang, & Chen, 2011; Gelfand et al., 1986; Liberman et al., 1956; Ohde & Sharf, 1977; Repp, Liberman, Eccardt & Pesetsky,1978; Wang, 1959).

In the present study, a marked difference in the error pattern before and after training was in the number of 'no responses'. Before the training the participants tended to not respond when unsure of a response, resulting in such responses being maximum compared to other feature errors. A notable change after temporal resolution training was in the reduction in 'no-responses'. After training, the participants attempted to respond more often instead of avoiding responding, as they did before the training. However, the percentage of feature errors (place, manner, voicing or combination of these), calculated as a percentage of errors without including the 'no responses', show only a marginal change with temporal resolution training [manner of articulation (74.84%) followed by place of articulation (54.71%) errors and voicing errors (43.39%)]. Thus, it can be seen that the ATRT programme did not have much of an effect on the percentage of errors noted by the participants as well as the pattern of errors. The manner of articulation errors continued to be higher compared to the place of articulation, which was higher than the voicing errors. Despite the minimal changes in the feature errors after training, with the reduction in the 'no responses' the total number of errors did decrease significantly. The significant reduction in the total number of phoneme errors after training augments the findings that the ATRT programme was helpful in improving the perception of phonemes in the presence of noise. It is possible that if the ATRT programme is provided for a longer duration, a more positive effect on feature errors may be evident.

Further, the reduction in the phoneme errors seen soon after cessation of temporal resolution training, continued to be present 4 weeks after the cessation of training. However, the actual values were not calculated as done for pre-training evaluation-1 and post-training evaluation-2 as the responses were obtained from only 10 of the 20 participants. The errors of these 10 participants at post-training evaluation-1 were different from that of the remaining 10 participants at the same evaluation. Hence, the percentage errors of the 10 participants were not provided for post-training evaluation-2 as a clear picture of the percentage errors would not have been possible. These errors would not have been a completely representative of the errors observed in the earlier observations. However, the pattern of errors remained the same after 4 weeks of cessation of training.

It can be concluded that null hypothesis *3g, "Temporal resolution training has no significant effect on phoneme error pattern in the presence of noise"* is rejected. However, null hypothesis *4g, "Temporal resolution training* results *has no significant* *difference on performance 4 weeks after cessation of training in phoneme error pattern in the presence of noise"* is accepted.

5.3.8 Effect of auditory temporal resolution training on speech evoked cortical responses

In the current study, the effect of ATRT programme on MMN was evaluated. In addition, the effect of the training programme was studied on the latency and amplitude of LLR responses.

It was found that MMN was absent in the majority of the individuals across the three evaluations. This absence persisted even after an offline removal of baseline EEG activity, to eliminate artefacts. The absence of MMN indicates that at the pre-attentive stage the older adults were not able to discriminate between the two CVs (/ṭa/ & /ḍa/) that differed in terms of voicing. This was observed although these older adults showed good voicing discrimination at a word level, evaluated in the voicing discrimination word test. The presence of additional redundant coarticulatory cues in the word test may have enabled the participants to perceive voicing distinction at the word level. Such redundant cues were not present in the in the CVs used for measuring MMN. This may have led to the absence of the cortical responses. It can also be inferred that the temporal resolution training was not sufficient to eliminate this difficulty in discrimination at the pre-attentive level.

In literature, MMN has been recorded for gaps embedded in a 1 kHz signal by Bertoli et al. (2002) in older adults. It can be speculated that MMNs can be recorded in older adults for gaps in stimuli that are not complex. However, temporal cues present in complex stimuli such as CVs may be difficult for this age group to discriminate and may result in an absence of MMN responses. Thus, the increased complexity in processing of the CV syllables compared to the processing of 1 kHz tone could had led to the absence of MMN in the current study.

MMN has also been recorded in older adults with the use of synthetic speech stimuli (Bellis et al., 2000). However, in the current study, natural stimuli spoken by an adult male was used. The natural stimuli would have been a lot more complex compared to the synthetic stimuli used by Bellis et al., which majorly varied only in terms of onset frequency of F3. This would have made the cues simpler compared to the complex signal used in the current study. This may have resulted in the absence of MMN responses in the current study.

Unlike the responses for MMN, the LLR was present for each of these CVs. The presence of LLR response and the absence of MMN could also be due the difference in generators. It has been reported by Näätänen and Picton (1987) that the generators for MMN and LLR are different. The generators reported for MMN include bilateral secondary auditory cortex including superior temporal gyrus, anterior Heschl's gyrus and with contributions from prefrontal cortex, thalamus and hippocampus (Alain, Woods, & Knight, 1998; Alho, 1995; Alho, Woods, Algazi, Knight, & Näätänen, 1994; Giard, Perrin, Pernier, & Bouchet, 1990). On the other hand, the generators reported for LLR mainly include the Heschl's gyrus in the primary auditory cortex (Huotilainen et al., 1998; Liégeois-Chauvel, Musolino, Badier, Marquis, & Chauvel, 1994; Pool, Finitzo, Hong, Rogers, & Pickett, 1989).

The latencies of N1 and P2 responses were observed to be differentially affected by ageing. When the latencies of these LLR responses of the older adults were compared with that obtained by Kumar and Jayaram (2005) for young adults using unprocessed /ḍa/ stimuli, it was observed that the latencies of N1 was similar. However, the latencies of P2 responses were prolonged when compared to that reported by Kumar and Jayaram for young adults.

With temporal resolution training, changes were observed in the latencies of LLR response i.e. N1 latencies showed a significant reduction after training using the ATRT programme all the three response acquisition sites. However, a similar change was not observed in the latencies P2 and in the amplitude of the N1-P2 complex. From these findings, it can be inferred that the ATRT programme was able to bring about changes in the cortical processing. However, it affected the regions responsible for N1 and P2 latencies differently.

Research by Michie, Bearpark, Crawford, and Glue (1990) and Michie, Solowij, Crawford, and Glue (1993) have shown that N1 and P2 are affected differentially by the attention paid towards stimuli. These studies have shown that P2 responses decrease when attention was paid towards the stimuli. However, in the current study such a change was not observed as P2 latencies did not change significantly with auditory temporal resolution training. Both before and after temporal resolution training, the recording was done while the adults watched a silent movie and they were asked to not pay attention to the auditory stimuli. Thus, it can be construed that their lack of attention towards the auditory stimuli could have resulted in no difference in P2 latency.

The change in the N1-P2 complex of the LLR responses observed in the present study is in contrast to the findings of Tremblay et al. (2001). They reported changes in the N1-P2 complex after training for VOT perception. With training, Tremblay et al. found changes in the amplitude of the N1-P2 complex but no change in the latencies of N1 and P2. However, in the current study only the latencies of N1 showed a decrease after training while no changes occurred in P2 latency and the amplitude of N1-P2 complex. The probable reason for this difference in finding could be the stimulus used for training and the age of the participants who were trained. Tremblay et al. used speech stimuli for training young adults in the age range of 21 to 31 years while in the current study nonverbal stimuli was used to train older adults in the age range of 55 to 75 years.

Hence, null hypothesis *3h, "Temporal resolution training has no significant effect on speech evoked cortical responses"* is rejected for latency of LLR and accepted for MMN and amplitude of LLR. The null hypothesis *4h, "temporal resolution training results in no significant difference on performance 4 weeks after cessation of training on Speech evoked cortical responses"* is accepted for both MMN and LLR.

From the overall findings of the study, it can be deduced that the changes observed in the responses of the participants after the ATRT programme serves as evidence for the presence of auditory plasticity in older adults. Plasticity related changes in older adults have been reported by numerous studies in the literature. These include changes in memory, cognitive functioning, auditory processing and speech in processing (Anderson, White-Schwoch, Choi, et al., 2013; Anderson, White-Schwoch, Parbery-Clark, et al., 2013; Mahncke et al., 2006; Morais et al., 2015).

Thus, from the findings of the study at hand it can be observed that the ATRT programme not only had a positive impact on the auditory process that was targeted at, but also on processes that were not aimed at during training. Transfer of learning took place from temporal resolution abilities to temporal patterning, binaural integration, and auditory separation/closure. In addition, the auditory memory span also showed improvements. The positive effect of the training was not only observed in the behavioural measures carried out, but also in one of the electrophysiological tests that was administered. This outcome augments the findings of Tremblay, Kraus, Carrell, and McGee (1997). They reported of ‘transfer of learning’ in young adults trained on discrimination of prevoiced labial stop to discrimination of prevoiced alveolar stop not present in their native language of English. Thus, it can be concluded that transfer of learning not only takes place in children and young adults, but also takes place in older adults.

The improvements seen in the current study in other auditory processes that were not tapped by the training programme can be attributed to an overlap of the cortical areas responsible for these auditory processes. This can be construed from the findings of Anton et al. (1996) who reported that the central sulcus was activated during hepatic discrimination of shape and finger movements. According to them, the overlap in the representations in the brain helps account for the plastic changes associated with learning. A similar overlap may also be present in the cortical areas representing auditory functions.

It can be construed from the findings of the current study that the ATRT programme was not only effective in helping the older adults overcome the difficulties in temporal resolution that was directly addressed but also difficulties in other auditory processes. The other auditory processes that showed improvement following the ATRT programme included temporal ordering, binaural integration, auditory separation / closure, and auditory memory. As these improvements in the behavioural tests were supported by physiological evidence of improvement, it is recommended that this programme be used to reduce the auditory processing difficulties in older individuals. The study also provides evidence for the presence of auditory plasticity in older individuals.

Chapter 6

SUMMARY AND CONCLUSIONS

Auditory processing abilities have been reported to decline with advance in age (Dubno et al., 1984; Gelfand et al., 1985; Gordon-Salant, 1986; Pedersen et al., 1991; Prosser et al., 1991; Strouse et al., 1998). Decline in *auditory temporal processing* has been noted to occur in several studies (Bertoli et al., 2002; Fink et al., 2005; Fitzgibbons et al., 2006; He et al., 1999; John et al., 2012; Pichora-Fuller et al., 2006; Roberts & Lister, 2004; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002; Trainor & Trehub, 1989; Vaidyanath & Yathiraj, 2015). Besides temporal deficits, older adults have been found to have problems in *binaural integration* (Cox et al., 2008; Jerger et al., 1995; Jerger et al., 1994; Roup et al., 2006), *auditory separation / closure* (Dubno et al., 1984; Gelfand et al., 1986; Pichora-Fuller et al., 1995; Prosser et al., 1991; Russo & Pichora-Fuller, 2008), and *binaural interaction* (Pichora-Fuller & Schneider, 1991; Strouse et al., 1998). Additionally deficits in cognitive functions like auditory memory have also been reported in older adults (Craik & Byrd, 1982; Grady & Craik, 2000; Old & Naveh-Benjamin, 2008; Salthouse, 1996a, 1996b). From the literature, it was evident that though numerous studies have confirmed the presence of auditory processing difficulties in older adults, research focussing on rehabilitation of these individuals with auditory processing deficits is sparse.

The current study was carried out with the aim to determine the efficacy of ‘Auditory Temporal Resolution Training programme (ATRT)’ in older adults with near normal hearing. This aim was established by studying the effect of the training programme on auditory processing (temporal resolution, temporal patterning, binaural integration, and auditory separation/closure), voicing discrimination, auditory memory and sequencing as well as electrophysiological responses. To address this aim, the performance of older adults before and after ATRT was compared on the tests of temporal processing, binaural integration, auditory separation / closure, voicing discrimination, as well as auditory memory and sequencing. Additionally, the older adults were evaluated using cortical potentials (MMN & LLR). To evaluate temporal processing, the participants were evaluated using Gap-In-noise test (GIN; Musiek et al., 2005), Gap detection test (GDT; Shivaprakash, 2003) and Duration pattern test (DPT; Musiek et al., 1990) Binaural integration was examined using Dichotic CV test (DCV; Yathiraj, 1999) and, auditory memory and sequencing using Kannada auditory memory and sequencing test, (KAMST; Yathiraj & Vijayalakshmi, 2006). Auditory separation / closure abilities was assessed using Speech-perception-in-noise test in Kannada (SPIN-K), and Voicing discrimination was tested using voicing discrimination word test in Kannada (VDWT), both developed as a part of the current study.

The ATRT programme, developed as part of the present study, consisted of four different stimuli types (broadband noise, 500 Hz NBN, 1000 Hz NBN & 2000 Hz NBN) and four levels having increasing complexity. The training for all participants commenced at level I and progressed to level IV. The training was terminated when the participant maintained a score of at least 80% for 3 successive training sessions at level IV. The number of training sessions administered for each participant varied from 7 sessions to 13 sessions.

A total of 49 participants in the age range of 55 to 75 years were initially evaluated. They were divided into two age groups with 39 individuals aged 55 to 64;11 years and 10 individuals aged 65 to 74;11 years. Out of the 49 participants, 20 older adults with deficits in temporal processing (temporal resolution & patterning) were trained using the ATRT programme.

To study the effectiveness of the ATRT programme, the participants were evaluated twice prior to the training (pre-training evaluation-1 & pre-training evaluation-2) and twice following the training (post-training evaluation-1 & post-training evaluation-2). A minimum gap of two weeks was maintained between the two pre-training evaluations and a gap of four weeks was maintained between the two post-training evaluations. All the behavioural tests of auditory processing (GIN, GDT, DPT, DCV, & SPIN-K), voicing discrimination as well as auditory memory and sequencing were administered in each of these pre-training and post-training evaluations. The electrophysiological responses (MMN & LLR) were obtained only in pre-training evaluation-2, post-training evaluations-1 and 2.

The data collected were analysed to obtain information about the effect of the two age groups (55 to 64;11 & 65 to 74;11 years), effect of ear / scoring procedure as well as effect of the training. This was obtained using Mann-Whitney test, Friedman test and Wilcoxon signed rank test for the data that did not follow a normal distribution and repeated measure ANOVA for the data that were normally distributed. Additionally, a comparison of the performance of the older adults in relation to available norms of young adults was carried out.

The major findings of the study are as follows:

- *Age groups:* Prior to the comparison of the pre-training and the post-training evaluations, the performance to the two age groups (55 to 64;11 and 65 to 74;11 years) were compared. No significant difference was found between the two groups, indicating that they performed similarly on the tests of auditory processing, voicing discrimination as well as auditory memory and sequencing. It also indicated that with advance in age further deterioration in auditory processing abilities was not present.

- *Pre-training performance:* The comparison of the two pre-training evaluations indicated that there was no significant difference in performance. From this it was construed that in the absence of training the performance of the older adults was not influenced by any external variables. This also indicated that the test-retest reliability of the behavioural tests were high.

- *Ear difference:* The presence of ear difference was evaluated on all the tests that were administered monaurally (GIN, GDT, DPT, SPIN-K & VDWT). A significant difference between the performances of the two ears was not observed in any of these tests.

- *Influence of ATRT on temporal resolution:* The performance of the older adults on tests of temporal resolution was found to be poorer than the norms for young adults on GIN given by Aravindkumar et al. (2012) and GDT given by Shivaprakash (2003). Following temporal resolution training, significant improvement was seen in the performance on both the tests of temporal resolution (GIN & GDT) that were administered. This was observed in the form of reduction in the gap detection thresholds and a reduction in the number of individuals who failed the two tests. This indicated that the participants were able to detect smaller duration gaps after training.

- *Influence of ATRT on temporal ordering:* Temporal ordering assessed using DPT showed enhanced performance after the ATRT programme. A significant improvement in the DPT scores as well as an increase in the number of individuals who obtained scores similar to the norms for young adults given by Gauri (2003) was observed. Thus, temporal resolution training improved temporal ordering abilities as well.

- *Influence of ATRT on binaural integration: Significant* improvement in the single correct scores of the right and left ears as well as double correct scores of the DCV were observed after temporal resolution training. This showed the positive impact of the training on binaural integration. However, several of the participants continued to obtain poorer scores compared to that of young adults reported by Prachi (2000).

- *Influence of ATRT on auditory separation / closure:* Auditory separation / closure abilities, assessed using SPIN-K, were also found to be positively affected in the older adults after training. The number of individuals with scores below the norms of Kalikow et al. (1977) reduced following temporal resolution training.

- *Influence of ATRT on voicing discrimination:* Unlike the improvements observed in other auditory processes following temporal resolution training, voicing discrimination abilities assessed using VDWT, did not show any change. The presence of a ceiling effect on the scores of the test prior to the training was considered as a reason for the absence of an improvement. The use of a more difficult test, with less redundant cues, is recommended to avoid such a ceiling effect.

- *Influence of ATRT on auditory memory and sequencing span:* The auditory memory span and the sequencing span obtained using KAMST were poorer than the norms given by Vaidyanath and Yathiraj (2014a) before the administration of the ATRT programme. Following training, the auditory memory span showed significant improvements, but not the auditory sequencing span. This indicated that ATRT had a positive impact on auditory memory span.

- *Influence of ATRT on cortical responses:* In addition to the changes observed in the behavioural tests, electrophysiological evidence in the form of reduction in the latencies of N1 of LLR following temporal resolution training was observed. However, a similar change in latency of P1 and amplitude of N1-P2 was not observed. Additionally, changes in MMN were also not observed following temporal resolution training. This difference in the responses of MMN and LLR were attributed to the differences in the generators of the two cortical responses.

- *Variability in performance:* In all the tests, variability in the scores were seen prior to administration of ATRT training as well as in the improvement observed following training. This showed that the initial difficulties of the participants varied, as did the amount of improvement.
- *Maintenance of training:* The improvements observed in temporal resolution, binaural integration, auditory separation / closure and auditory memory span were maintained 4 weeks post cessation of temporal resolution training.
- *Generalization of temporal resolution training to other processes:* From the results of the study, it was concluded that the ATRT programme was effective in training older adults with auditory processing deficits. This was not only effective in improving the temporal resolution abilities that it directly tapped but also other auditory processes including temporal ordering, binaural integration, auditory separation / closure, and higher cognitive process (auditory memory).

The positive changes observed in the responses of the older adults following ATRT programme provides evidence for the presence of auditory plasticity in these individuals. The results also indicate that transfer of learning from temporal resolution abilities to temporal patterning, binaural integration, and auditory separation / closure.

Hence, it is recommended that ATRT programme be used in older adults to overcome the effects of ageing on auditory processing abilities.

Implications of the study:

The implications of the study are as follows:

- The study adds information to the existing corpus of information regarding the auditory processes that are deviant in older adults.
- The study proves that direct remediation activities are useful not only in children but also in older adults.
- Specific auditory training brings about change not only in the process that is targeted but also in other processes.
- The reduction in LLR latencies indicates that the developed training material does bring about changes in cortical responses.
- The findings of the study prove that auditory training does result in auditory plasticity even in older adults.
- The developed training material that has been proven to be useful will be helpful in rehabilitating adults who have temporal processing problems. It will also be helpful for other auditory processing / higher cognitive problems such as auditory separation, auditory integration, and auditory memory problems.

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APPENDIX- I

Details of the instructions, training material and scoring for the Auditory Temporal Resolution Training (ATRT) programme

Overview of the ATRT programme

The ATRT program is designed for individuals with temporal resolution deficits. Although it is designed for adults, by modifying the instructions, it can also be used in children. The stimuli consist of broadband and narrowband noise segments with gaps embedded in them. It is made-up of 4 increasing levels of difficulty (Enclosure A). At each level, 4 different noise types are used (broadband noise, 500 Hz narrowband noise, 1000 Hz narrowband noise, & 2000 Hz narrowband noise). It is recommended that the training commences at level 1, irrespective of the severity of temporal processing difficulty. An individual can progress to the next level if they achieve a score of at least 80% correct gap identification in a particular level.

To run the ATRT programme, a computer is required having processing speed fast enough to play audio and visual signals. The computer is required to play the recorded stimuli of the training programme, which is heard by the participants via a good quality headphone capable of delivering binaural output . The stimuli can be played and the responses can be obtained in two different ways. If an APEX software is available, the stimuli can be played as well as the responses can be recoded and scored using the same software. However, if the APEX software is not available, the computer can be used to play the stimuli using any audio media software and oral responses of the participant can be noted on a sheet of paper. These responses would have to be scored manually later using a ‘Stimuli answer key’ (Enclosure B).

To administer the training programme using the APEX software, a computer with APEX 3 software installed is required. APEX 3 software is used to present the stimuli to the participant and to record their responses. The software is designed such that irrespective of the level, each gap duration is presented 10 times. The same software is also used to obtain responses from an individual as well as score the responses. To recode the responses, the individual is required to click on one of numbers displayed on the computer screen (Eg. 1, 2 or 1, 2, 3 or 1, 2, 3, 4 depending on the level) to indicate which of the stimuli contained a gap. The software is designed to provide feedback to the participant each time he/she responds. If the participant's response is correct it displays a 'thumbs-up' sign and if the response is wrong then a 'thumbs-down' sign is displayed and the correct alternative is highlighted on the computer screen. Any other display indicating a positive or a negative response can also be selected from the APEX software.

If the APEX 3 software is not available, any software capable of playing a .wav (wave file) may be used. In this case, the clinician has to have the 'Stimuli answer key' (a list containing information about which stimulus in a stimuli-set has a gap) for each level separately, note the responses of the participant manually and calculate the total percentage of gaps identified correctly. The clinician would also have to provide feedback to the participant if the response is correct or wrong immediately after it is provided.

A brief outline of the four levels of the training program is given below:

Level I

Material description:

Level I in the training programme consists of 6 sets of 300 ms stimuli with gap durations varying from 30 ms to 20 ms embedded in broadband and the narrow band noise segments. The stimuli in level I are presented in pairs (2-stimuli sequence) with one stimulus of a pair containing a gap and the other containing no gap. The gap duration decreases in steps of 2 ms from one set to the other. Each stimulus-set is presented 10 times making the total number of presentations 60 for each of the four noise types (BBN, 500 Hz NBN, 1000 Hz NBN and 2000 Hz NBN).

Instructions to the clinician:

If APEX 3 software is used: Tell the participant that he/she will hear two stimuli and one out of the two will have a gap in them. The participant has to click using a mouse on the number of the stimulus that contains the gap among the two stimuli that are presented. A screen shot of the display is proved in Figure 1. Demonstration needs to be provided to the participants regarding how they are to select the response from the display shown in the computer screen, prior to commencing the training. Tell the participant that he/she will hear the next stimulus-set only after a response is provided to the previous stimulus-set. If he/she are not sure about the response, encourage him/her to guess the response.

If APEX 3 software is not used: Tell the participant that he/she will hear two stimuli out of which one will have a gap inserted into it. Ask the participant to tell you which of the two stimuli presented contained a gap. If he/she is not sure about the response, encourage him/her to guess the response. Manually note the responses provided by the participant for scoring later.

Instructions to the participant:

"You will hear two stimuli. One of them will have a gap in it. You have to click on the numbers '1' or '2' displayed on the screen using a mouse, depending on whether it is the first or the second sound that has a gap (for those using a computer software) / tell me if the first or the second stimulus has a gap (for those who give an oral response) . You will hear the next stimuli only after a response is provided to the previous stimuli. If you are not sure about the response then try guess the correct response".

Feedback and reinforcement:

If APEX 3 software is used: Feedback is provided by the software for each response provided by the participant as soon as the participant responds. If the response is correct, a 'thumbs-up' sign appears on the screen. If the response provided is incorrect, a 'thumbs-down' sign appears on the screen and the correct stimuli-alternative is highlighted.

If APEX 3 software is not used: Feedback is provided by the tester for each response provided by the participant. This should be provided as soon as the participant responds.

Scoring:

If APEX 3 software is used: The APEX 3 software will automatically gives a score of 1 for each correct response and a score of 0 for each incorrect response. After the completion of the training, the software calculates the total number of correct responses and percentage of correct identification. This is displayed with the information about each stimulus that was presented, the expected response, and the response provided by the participants.

If APEX 3 software is not used: Depending on the response of the participant each correct response should be given a score of 1 and a score of 0 for each incorrect response. The total percentage of correct responses should be calculated by dividing it by the total number of stimuli presented.

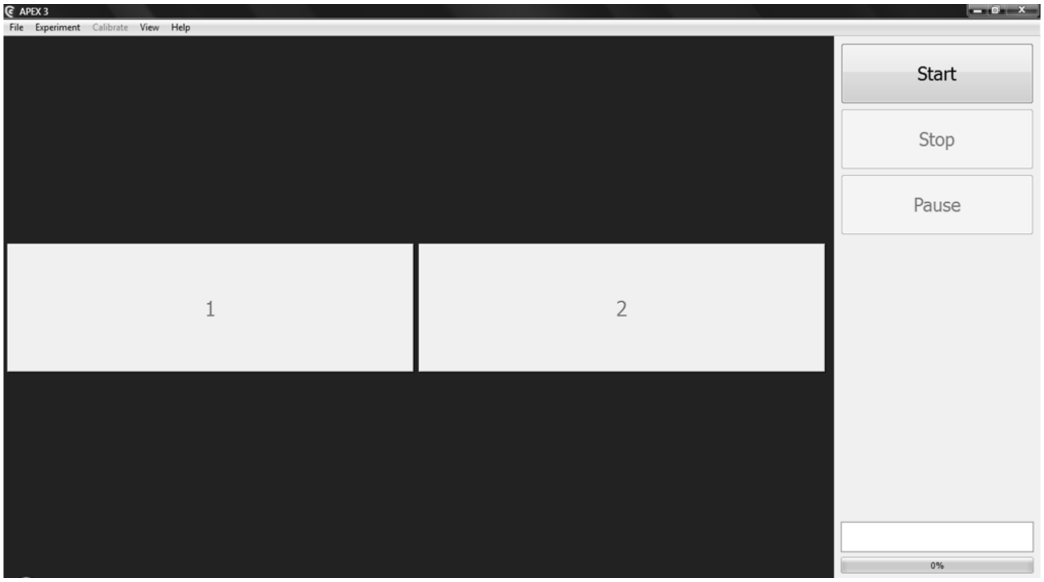


Figure 1. Screenshot of the software used for stimulus presentation in Levels I and II.

Table 1
Stimuli-set used in level I with duration of gap embedded in the four types of noise used (broadband noise, BBN; 500 Hz narrowband noise, 500 Hz NBN; 1000 Hz narrowband noise, 1000 Hz NBN; 2000 Hz narrowband noise, 2000 Hz NBN)

Set No.	**Type of noise burst**	**Duration of noise burst**	**Stimuli sequence**	**Duration of gap**	**No. of presentations**
Level I					
1.	BBN	300 ms	2-stimuli sequence	30	10
2.		300 ms	2-stimuli sequence	28	10
3.		300 ms	2-stimuli sequence	26	10
4.		300 ms	2-stimuli sequence	24	10
5.		300 ms	2-stimuli sequence	22	10
6.		300 ms	2-stimuli sequence	20	10
Total no. of presentations for BBN in Level I					**60**
1.	500 Hz NBN	300 ms	2-stimuli sequence	30	10
2.		300 ms	2-stimuli sequence	28	10
3.		300 ms	2-stimuli sequence	26	10
4.		300 ms	2-stimuli sequence	24	10
5.		300 ms	2-stimuli sequence	22	10

6.		300 ms	2-stimuli sequence	20	10
Total no. of presentations for 500 Hz BBN in Level I					**60**
1.	1000 Hz NBN	300 ms	2-stimuli sequence	30	10
2.		300 ms	2-stimuli sequence	28	10
3.		300 ms	2-stimuli sequence	26	10
4.		300 ms	2-stimuli sequence	24	10
5.		300 ms	2-stimuli sequence	22	10
6.		300 ms	2-stimuli sequence	20	10
Total no. of presentations for 1000 Hz NBN in Level I					**60**
1.	2000 Hz NBN	300 ms	2-stimuli sequence	30	10
2.		300 ms	2-stimuli sequence	28	10
3.		300 ms	2-stimuli sequence	26	10
4.		300 ms	2-stimuli sequence	24	10
5.		300 ms	2-stimuli sequence	22	10
6.		300 ms	2-stimuli sequence	20	10
Total no. of presentations for 2000 Hz NBN in Level I					**60**
Total no. of presentations in Level I					**240**

Level II

Material description:

Level II is initiated after the completion of Level I. This level is similar to level I except the duration of the stimuli used is 200 ms. This level consists of 6 stimuli-sets having 2-stimuli sequences. Each set, having different durations of gaps and each presented 10 times. Thus, each type of noise had a total of 60 presentations. The instructions, feedback and reinforcement as well as scoring for Level II are similar to that provided for Level I.

Instructions to the clinician:

If APEX 3 software is used: Tell the participant that he/she will hear two stimuli and one out of the two will have a gap in them. The participant has to click using a mouse on the number of the stimulus that contains the gap among the two stimuli that are presented. A screen shot of the display is proved in Figure 1. Demonstration needs to be provided to the participants regarding how they are to select the response from the display shown in the computer screen, prior to commencing the training. Tell the participant that he/she will hear the next stimulus-set only after a response is provided to the previous stimulus-set. If he/she are not sure about the response, encourage him/her to guess the response.

If APEX 3 software is not used: Tell the participant that he/she will hear two stimuli out of which one will have a gap inserted into it. Ask the participant to tell you which of the two stimuli presented contained a gap. If he/she is not sure about the response, encourage him/her to guess the response. Manually note the responses provided by the participant for scoring later.

Instructions to the participant:

“You will hear two stimuli. One of them will have a gap in it. You have to click on the numbers ‘1’ or ‘2’ displayed on the screen using a mouse, depending on whether it is the first or the second sound that has a gap (for those using a computer software) / tell me if the first or the second stimulus has a gap (for those who give an oral response) . You will hear the next stimuli only after a response is provided to the previous stimuli. If you are not sure about the response then try guess the correct response”.

Feedback and reinforcement:

If APEX 3 software is used: Feedback is provided by the software for each response provided by the participant as soon as the participant responds. If the response is correct, a ‘thumbs-up’ sign appears on the screen. If the response provided is incorrect, a ‘thumbs-down’ sign appears on the screen and the correct stimuli-alternative is highlighted.

If APEX 3 software is not used: Feedback is provided by the tester for each response provided by the participant. This should be provided as soon as the participant responds.

Scoring:

If APEX 3 software is used: The APEX 3 software will automatically gives a score of 1 for each correct response and a score of 0 for each incorrect response. After the completion of the training, the software calculates the total number of correct responses and percentage of correct identification. This is displayed with the information about each stimulus that was presented, the expected response, and the response provided by the participants.

If APEX 3 software is not used: Depending on the response of the participant each correct response should be given a score of 1 and a score of 0 for each incorrect response. The total percentage of correct responses should be calculated by dividing it by the total number of stimuli presented.

Table 2
Stimuli-set used in level II with duration of gap embedded in the four types of noise used (broadband noise, BBN; 500 Hz narrowband noise, 500 Hz NBN; 1000 Hz narrowband noise, 1000 Hz NBN; 2000 Hz narrowband noise, 2000 Hz NBN)

Level II					
1.	BBN	200 ms	2-stimuli sequence	20	10
2.		200 ms	2-stimuli sequence	18	10
3.		200 ms	2-stimuli sequence	16	10
4.		200 ms	2-stimuli sequence	14	10
5.		200 ms	2-stimuli sequence	12	10
6.		200 ms	2-stimuli sequence	10	10
Total no. of presentations for BBN in Level II					**60**
1.	500 Hz	200 ms	2-stimuli	20	10

	NBN		sequence		
2.		200 ms	2-stimuli sequence	18	10
3.		200 ms	2-stimuli sequence	16	10
4.		200 ms	2-stimuli sequence	14	10
5.		200 ms	2-stimuli sequence	12	10
6.		200 ms	2-stimuli sequence	10	10
Total no. of presentations for 500 Hz NBN in Level II					**60**
1.	1000 Hz NBN	200 ms	2-stimuli sequence	20	10
2.		200 ms	2-stimuli sequence	18	10
3.		200 ms	2-stimuli sequence	16	10
4.		200 ms	2-stimuli sequence	14	10
5.		200 ms	2-stimuli sequence	12	10
6.		200 ms	2-stimuli sequence	10	10
Total no. of presentations for 1000 Hz BBN in Level II					**60**
1.	2000 Hz NBN	200 ms	2-stimuli sequence	20	10
2.		200 ms	2-stimuli sequence	18	10

3.		200 ms	2-stimuli sequence	16	10
4.		200 ms	2-stimuli sequence	14	10
5.		200 ms	2-stimuli sequence	12	10
6.		200 ms	2-stimuli sequence	10	10
Total no. of presentations for 2000 Hz NBN in Level II					**60**
Total no. of presentations in Level II					**240**

Level III

Material description:

The Level III of the training program is initiated after completion of Level II. This level contains 3-stimuli sequences with 11 stimulus-sets. Each set is repeated 10 times and each of the four noise types has 110 stimuli presentations. The duration of the noise bursts is 200 ms with gaps of 16 ms to 3 ms duration embedded in them. One stimulus out of the three presented in a sequence contains a gap.

Instructions to the clinician:

If APEX 3 software is used: Tell the participant that he/she will hear three stimuli and one out of the three will have a gap in them. The participant has to click using a mouse on the number of the stimulus that contains the gap among the three stimuli that are presented. A screen shot of the display is proved in Figure 2. Demonstration needs to be provided to the participants regarding how they are to select the response from the display shown in the computer screen, prior to commencing the training. Tell the participant that he/she will hear the next stimulus-set only after a response is provided to the previous stimulus-set. If he/she are not sure about the response, encourage him/her to guess the response.

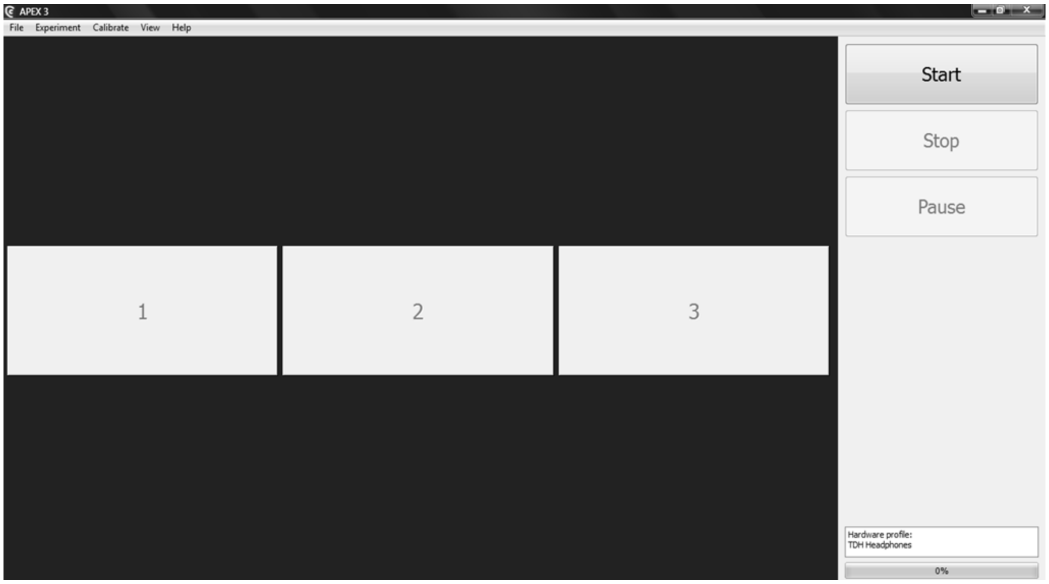
If APEX 3 software is not used: Tell the participant that he/she will hear three stimuli out of which one will have a gap inserted into it. Ask the participant to tell you which of the three stimuli presented contains a gap. If he/she is not sure about the response, encourage him/her to guess the response. Manually note the responses provided by the participant for scoring later.

Instructions to the participant:

“You will hear three stimuli. One of them will have a gap in it. You have to click on the numbers ‘1’, ‘2’ or ‘3’ displayed on the screen using a mouse, depending on whether it is the first, second or the third sound that has a gap (for those using a computer software) / tell me if the first, second or the third stimulus has a gap (for those who give an oral response). You will hear the next stimuli only after a response is provided to the previous stimuli. If you are not sure about the response then try guess the correct response”.

Feedback, reinforcement and scoring:

The feedback and reinforcement provided are similar to that used in Level I. The Scoring also is similar to that used in Level I.



Hardware profile:
TDH Headphones

Figure 2. Screenshot of the software used for stimulus presentation in Level III.

Table 3
Stimuli-set used in level III with duration of gap embedded in the four types of noise used (broadband noise, BBN; 500 Hz narrowband noise, 500 Hz NBN; 1000 Hz narrowband noise, 1000 Hz NBN; 2000 Hz narrowband noise, 2000 Hz NBN)

Level III					
1.	BBN	200 ms	3-stimuli sequence	16	10
2.		200 ms	3-stimuli sequence	14	10
3.		200 ms	3-stimuli sequence	12	10
4.		200 ms	3-stimuli sequence	10	10
5.		200 ms	3-stimuli sequence	9	10
6.		200 ms	3-stimuli sequence	8	10
7.		200 ms	3-stimuli sequence	7	10

8.		200 ms	3-stimuli sequence	6	10
9.		200 ms	3-stimuli sequence	5	10
10.		200 ms	3-stimuli sequence	4	10
11.		200 ms	3-stimuli sequence	3	10
Total no. of presentations for BBN in Level III					**110**
1.	500 Hz NBN	200 ms	3-stimuli sequence	16	10
2.		200 ms	3-stimuli sequence	14	10
3.		200 ms	3-stimuli sequence	12	10
4.		200 ms	3-stimuli sequence	10	10
5.		200 ms	3-stimuli sequence	9	10
6.		200 ms	3-stimuli sequence	8	10
7.		200 ms	3-stimuli sequence	7	10
8.		200 ms	3-stimuli sequence	6	10
9.		200 ms	3-stimuli sequence	5	10
10.		200 ms	3-stimuli sequence	4	10

11.		200 ms	3-stimuli sequence	3	10
Total no. of presentations for 500 Hz NBN in Level III					**110**
1.	1000 Hz NBN	200 ms	3-stimuli sequence	16	10
2.		200 ms	3-stimuli sequence	14	10
3.		200 ms	3-stimuli sequence	12	10
4.		200 ms	3-stimuli sequence	10	10
5.		200 ms	3-stimuli sequence	9	10
6.		200 ms	3-stimuli sequence	8	10
7.		200 ms	3-stimuli sequence	7	10
8.		200 ms	3-stimuli sequence	6	10
9.		200 ms	3-stimuli sequence	5	10
10.		200 ms	3-stimuli sequence	4	10
11.		200 ms	3-stimuli sequence	3	10
Total no. of presentations for 1000 Hz NBN in Level III					**110**
1.	2000 Hz NBN	200 ms	3-stimuli sequence	16	10
2.		200 ms	3-stimuli sequence	14	10

3.		200 ms	3-stimuli sequence	12	10
4.		200 ms	3-stimuli sequence	10	10
5.		200 ms	3-stimuli sequence	9	10
6.		200 ms	3-stimuli sequence	8	10
7.		200 ms	3-stimuli sequence	7	10
8.		200 ms	3-stimuli sequence	6	10
9.		200 ms	3-stimuli sequence	5	10
10.		200 ms	3-stimuli sequence	4	10
11.		200 ms	3-stimuli sequence	3	10
Total no. of presentations for 200 Hz NBN in Level III					**110**
Total no. of presentations in Level III					**440**

Level IV

Material description:

The Level IV of the training program is initiated after completion of Level III. In this level 8 stimulus-sets are presented in a 4-stimuli sequence. Each stimulus-set has 10 presentations for each of the 4 types of noise bursts. Thus, each noise type has 80 presentations. The noise bursts have duration of 200 ms with 10 ms to 3 ms gaps embedded within them. One stimulus among the four that is presented contains a gap.

Instructions to the clinician:

If APEX 3 software is used: Tell the participant that he/she will hear four stimuli and one out of the four will have a gap in them. The participant has to click using a mouse on the number of the stimulus that contains the gap among the four stimuli that are presented. A screen shot of the display is proved in Figure 3. Demonstration needs to be provided to the participants regarding how they are to select the response from the display shown in the computer screen, prior to commencing the training. Tell the participant that he/she will hear the next stimulus-set only after a response is provided to the previous stimulus-set. If he/she is not sure about the response, encourage him/her to guess the response.

If APEX 3 software is not used: Tell the participant that he/she will hear four stimuli out of which one will have a gap inserted into it. Ask the participant to tell you which of the four stimuli presented contained a gap. If he/she is not sure about the response, encourage him/her to guess the response. Manually note the responses provided by the participant for scoring later.

Instructions to the participant:

“You will hear four stimuli. One of them will have a gap in it. You have to click on the numbers ‘1’, ‘2’, ‘3’ or ‘4’ displayed on the screen using a mouse, depending on whether it is the first, second, third or the fourth sound that has a gap (for those using a computer software) / tell me if the first, second, third or the fourth stimulus has a gap (for those who give an oral response). You will hear the next stimuli only after a response is provided to the previous stimuli. If you are not sure about the response then try guess the correct response".

Feedback, reinforcement and scoring:

The feedback and reinforcement provided are similar to that used in Level I. The Scoring also is similar to that used in Level I.

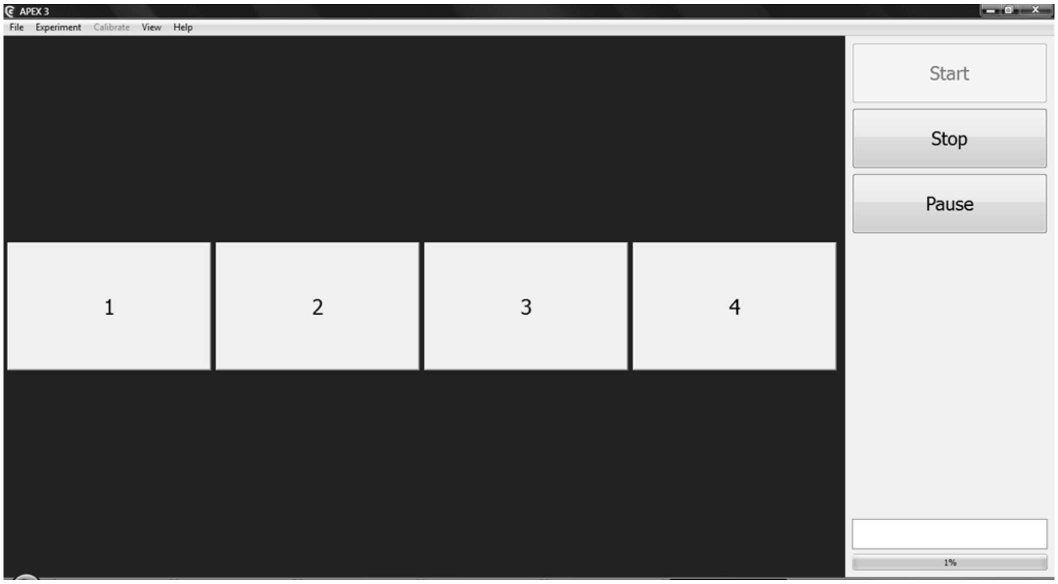


Figure 3. Screenshot of the software used for stimulus presentation in Level IV

Table 4

Stimuli-set used in level IV with duration of gap embedded in the four types of noise used (broadband noise, BBN; 500 Hz narrowband noise, 500 Hz NBN; 1000 Hz narrowband noise, 1000 Hz NBN; 2000 Hz narrowband noise, 2000 Hz NBN)

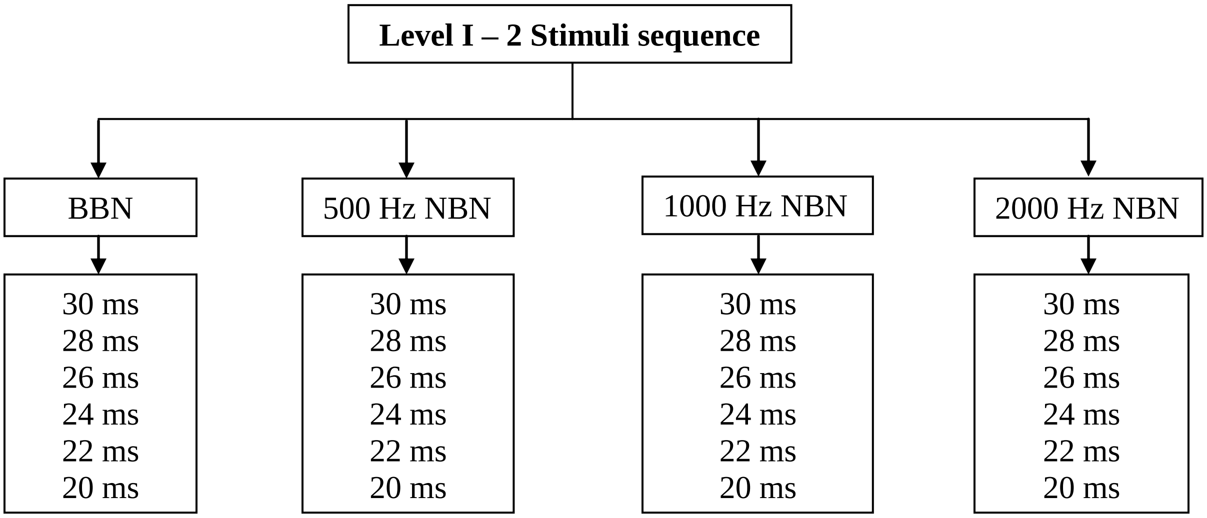
Level IV					
1.	BBN	200 ms	4-stimuli sequence	10	10
2.		200 ms	4-stimuli sequence	9	10
3.		200 ms	4-stimuli sequence	8	10
4.		200 ms	4-stimuli sequence	7	10
5.		200 ms	4-stimuli sequence	6	10
6.		200 ms	4-stimuli sequence	5	10
7.		200 ms	4-stimuli sequence	4	10
8.		200 ms	4-stimuli sequence	3	10
Total no. of presentations for BBN in Level IV					**80**
1.	500 Hz NBN	200 ms	4-stimuli sequence	10	10
2.		200 ms	4-stimuli sequence	9	10
3.		200 ms	4-stimuli sequence	8	10
4.		200 ms	4-stimuli sequence	7	10

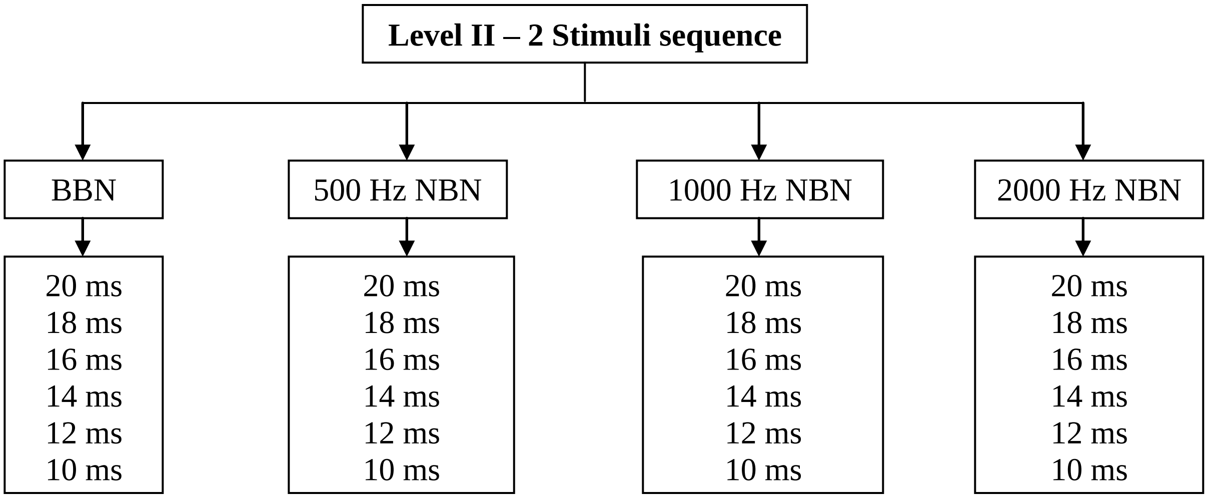
5.		200 ms	4-stimuli sequence	6	10
6.		200 ms	4-stimuli sequence	5	10
7.		200 ms	4-stimuli sequence	4	10
8.		200 ms	4-stimuli sequence	3	10
Total no. of presentations for 500 Hz NBN in Level IV					**80**
1.	1000 Hz NBN	200 ms	4-stimuli sequence	10	10
2.		200 ms	4-stimuli sequence	9	10
3.		200 ms	4-stimuli sequence	8	10
4.		200 ms	4-stimuli sequence	7	10
5.		200 ms	4-stimuli sequence	6	10
6.		200 ms	4-stimuli sequence	5	10
7.		200 ms	4-stimuli sequence	4	10
8.		200 ms	4-stimuli sequence	3	10
Total no. of presentations for 1000 Hz NBN in Level IV					**80**
1.	2000 Hz NBN	200 ms	4-stimuli sequence	10	10
2.		200 ms	4-stimuli sequence	9	10

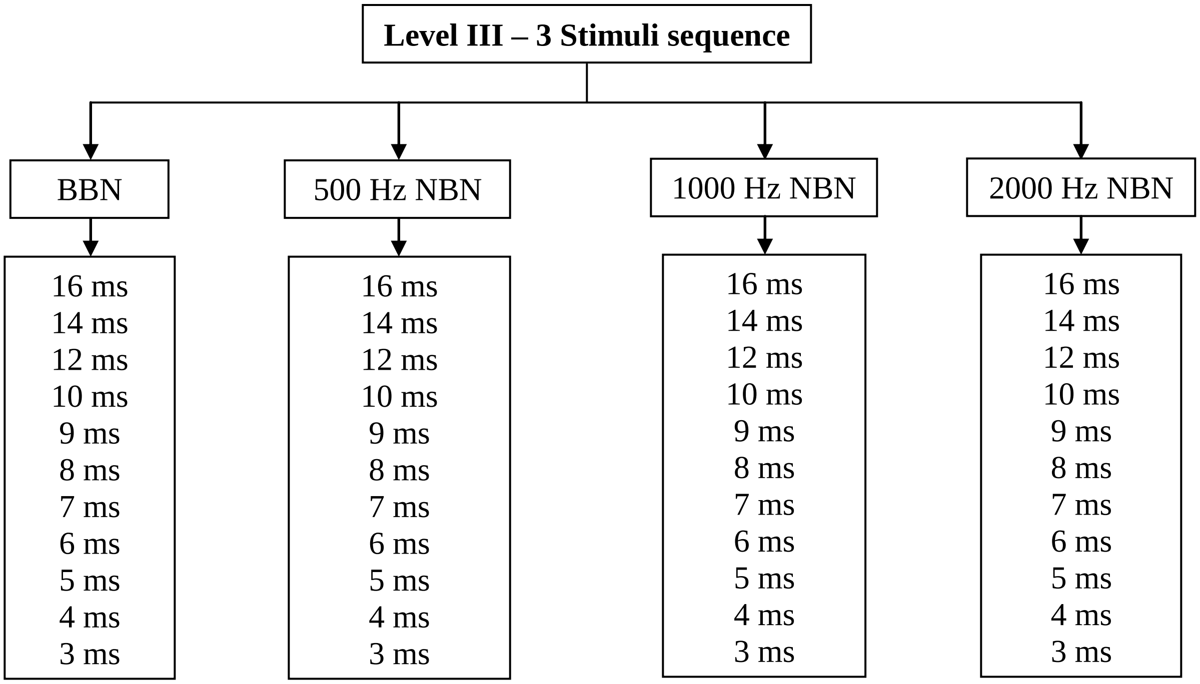
3.		200 ms	4-stimuli sequence	8	10
4.		200 ms	4-stimuli sequence	7	10
5.		200 ms	4-stimuli sequence	6	10
6.		200 ms	4-stimuli sequence	5	10
7.		200 ms	4-stimuli sequence	4	10
8.		200 ms	4-stimuli sequence	3	10
Total no. of presentations for 2000 Hz NBN in Level IV					**80**
Total no. of presentations NBN in Level IV					**320**

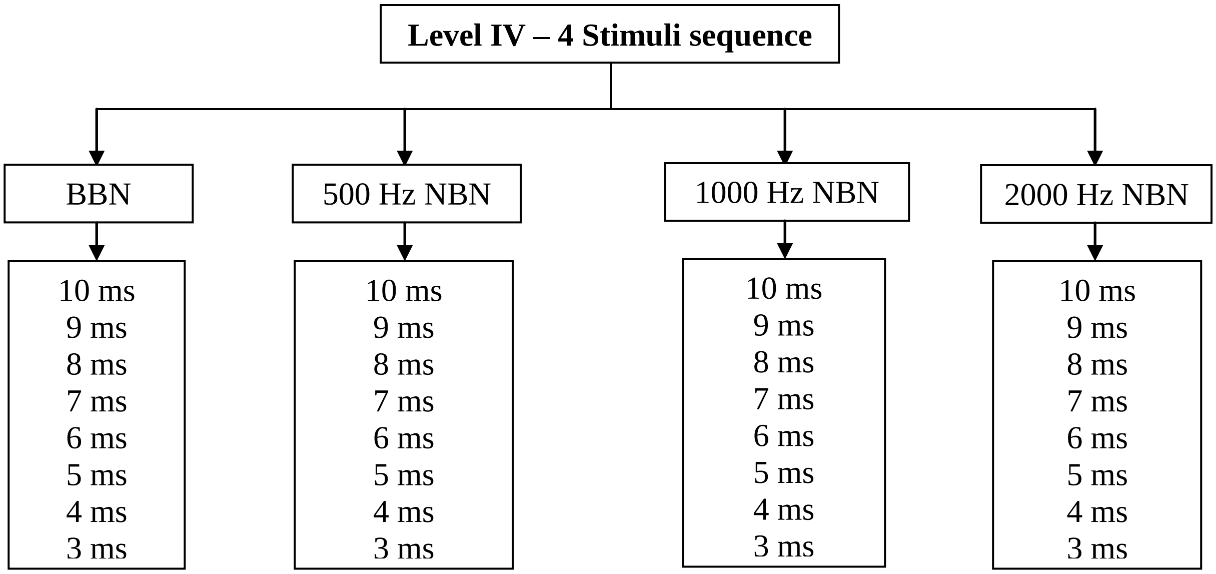
Enclosure A

Flowchart depicting the four levels of the Auditory Temporal Resolution Training programme




Level II – 2 Stimuli sequence
BBN
20 ms
18 ms
16 ms
14 ms
12 ms
10 ms
500 Hz NBN
20 ms
18 ms
16 ms
14 ms
12 ms
10 ms
1000 Hz NBN
20 ms
18 ms
16 ms
14 ms
12 ms
10 ms
2000 Hz NBN
20 ms
18 ms
16 ms
14 ms
12 ms
10 ms


Level III – 3 Stimuli sequence
BBN
16 ms
14 ms
12 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
500 Hz NBN
16 ms
14 ms
12 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
1000 Hz NBN
16 ms
14 ms
12 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
2000 Hz NBN
16 ms
14 ms
12 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms


Level IV – 4 Stimuli sequence
BBN
500 Hz NBN
1000 Hz NBN
2000 Hz NBN
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms
10 ms
9 ms
8 ms
7 ms
6 ms
5 ms
4 ms
3 ms

Enclosure B

Auditory temporal resolution training stimuli-Answer Key

Stimulus number	Level I	Level II	Level III	Level IV
1	1	2	1	1
2	2	1	2	3
3	1	2	3	2
4	1	2	2	4
5	1	1	3	1
6	2	2	1	2
7	2	2	2	3
8	2	1	3	2
9	2	2	2	2
10	1	1	3	4
11	2	2	2	3
12	1	1	3	2
13	2	2	2	2
14	2	1	2	3
15	1	2	3	1
16	2	2	2	3
17	2	1	3	2
18	1	2	3	4
19	2	2	2	1
20	1	1	3	2

21	1	2	2	3
22	2	1	2	2
23	1	1	3	2
24	1	2	1	4
25	1	1	2	3
26	2	2	3	2
27	2	1	2	2
28	2	2	3	3
29	2	1	2	4
30	1	2	3	1
31	2	2	2	2
32	1	1	2	3
33	2	1	3	2
34	2	1	2	2
35	1	2	3	4
36	2	2	3	3
37	2	2	2	2
38	1	2	1	2
39	2	1	2	3
40	1	2	3	1
41	2	1	2	3
42	1	2	3	2
43	2	2	1	4
44	1	1	2	1

45	2	2	3	2
46	2	2	2	4
47	1	1	3	1
48	2	2	2	2
49	2	1	3	3
50	1	2	2	2
51	2	1	3	2
52	1	2	1	4
53	1	1	2	3
54	2	2	3	2
55	1	2	2	2
56	2	1	3	3
57	1	2	2	4
58	2	2	3	1
59	1	1	2	2
60	2	2	2	3
61			3	2
62			2	2
63			3	3
64			3	4
65			2	1
66			1	2
67			2	3
68			3	2

69			2	2
70			3	4
71			2	3
72			3	2
73			2	2
74			3	3
75			2	1
76			3	3
77			1	2
78			2	4
79			3	1
80			2	2
81				4
82				1
83				2
84				3
85				2
86				2
87				4
88				3
89				3
90				4
91				1
92				2

93				3
94				2
95				2
96				3
97				4
98				1
99				2
100				3
101				2
102				2
103				4
104				3
105				2
106				2
107				3
108				1
109				3
110				2