Temporal Ability Screening Test (TAST): Development and validation

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Funding Agency: AIISH Research Fund

(Ref: SH/CDN/ARF/4.69/2013-14 dated 30/08/13)

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MYSORE

2016 January

Abstract

Objectives: *The study was designed to develop and validate a test for screening deficits in temporal abilities. The study also investigated if there is any difference in the temporal abilities of native speakers of Kannada, an Indo-Dravidian language and native speakers of Marathi, an Indo-Aryan language.*

Design: *A screening tool 'Temporal ability screening test (TAST)', consisting of three subsections [Gap Detection in Noise (GIN), Duration Discrimination (DD) and Duration Pattern (DP)] was initially developed. The screening test and diagnostic versions of the tests were administered on 260 participants in two centres, one in Karnataka and the other in Maharashtra. Participants with normal hearing were aged 20 to 30 years (Group I YA), 50 to 60 years (Group I OAa) and 60 to 70 years (Group I OAb). Participants with mild to moderate sensorinerual hearing loss were aged 50 to 60 years (Group II OAa) and 60 to 70 years (Group II OAb).*

Results: *No significant difference was found between native speakers of Kannada and Marathi for two of the diagnostic temporal processing test (GIN & DPT), but was present for DD. There was no significant difference between males and females as well as ears of the young adults. Maximum number of individuals were referred in the GIN subsection of TAST, followed by DD and DP. On the diagnostic temporal processing tests, the majority failed either GIN or DD and very few failed DPT. The sensitivity of subsections of TAST varied; GIN had the highest sensitivity (93.7%), followed by DD (70.35%) and DPT had the least sensitivity (60.41%). The specificity for all the subsections was high (above 90%).*

Conclusions: *In most of the parameters studied there was no difference between Kannada and Marathi speakers. The newly developed screening test, TAST was useful in detecting temporal processing deficits in normal hearing individuals as well as those with hearing impairment.*

1. Introduction

It is well documented that perception of speech and music depend a lot on the temporal processing skill of the auditory system, as time related changes are an integral part of these stimuli. Shinn (2003) reported that temporal processing was involved in most of the central auditory processes. Hence, it can be construed that temporal processing is essential for perception of speech and non-speech stimuli.

It has been reported by Yin and Chan (1990) and Konishi (2003) that the auditory system is structurally organized to process fine temporal features. Different structures in the auditory system have been found to be specialized to respond to different temporal features. Konishi noted that cells in the medial superior olive were sensitive to interaural time differences and cells in the lateral superior olive were sensitive to interaural intensity differences. Cells specialized in processing sounds with various temporal characteristics like transient stimuli, rapidly changing stimuli were identified. These cells were also found to have the capacity to process signals coming ipsilaterally or contralaterally to extract further information.

As per the American Speech-Language-Hearing Association (2005), temporal processing of audition signals include temporal integration, temporal discrimination, temporal ordering and temporal masking. Auditory temporal processes have also been subcategorized by Musiek et al. (2005b) and Shinn (2003) as temporal masking, temporal ordering or sequencing, temporal integration or summation, and temporal resolution or discrimination.

According to Pinheiro and Musiek (1985) *temporal ordering or sequencing* involves processing of several auditory stimuli in the order in which they occur. Shinn (2003) reported that despite temporal ordering being extensively investigated, it is affected by several variables. These include the number of stimuli, simultaneous or continuous presentation of sequences, the response mode, and amount of training. Despite temporal ordering being found to be influenced by several variables, this process continues to be considered important since accurate temporal order judgment has been found to be important for speech perception (Rawool, 2013; Warren & Obusek, 1972) and music (Fitzgibbons & Gordon-Salant, 1998; Rawool, 2013; Warren & Obusek, 1972). The assessment of temporal ordering/patterning has been noted to help identify inter-hemispheric dysfunction and lesions in the two hemispheres of the brain (Musiek, Baran, & Pinheiro, 1990a; Musiek & Pinheiro, 1987). Pitch Pattern Test (Pinheiro & Ptacek, 1971) and

Duration Pattern Test [DPT, (Musiek et al., 1990a)] are commonly used to assess temporal ordering skills. The Duration Pattern Test has been the preferred test to assess temporal ordering in persons having peripheral hearing loss. Research has shown that this is not affected by mild to moderate hearing loss (Musiek et al., 1990a). In India, norms for DPT for adults were first provided by Gauri (2003). However, only 10 adults aged 18 to 35 years were studied. Norms on a larger group of normal hearing adults was provided by Mohan and Yathiraj (2015). Three groups of adults were studied (18 to 30 years, 55 to 60 years, & 66 to 75 years). They observed that age did affect performance. While the youngest age group obtained scores of 97.6% (SD = 1.5 to 1.8 for the right & left ears respectively), the oldest group got mean scores of 83.6% (SD = 0.8) for the right ear and 82.6% (SD = 0.9) for the left ear.

Temporal discrimination or resolution, according to Shinn (2003) is the "shortest time in which a person can discriminate between two auditory signals" (p. 52). It is also considered as the shortest time interval that can be resolved and hence used to measure temporal resolution (Gelfand, 2010). For broadband noise signals, this was reported to approximately 2 to 3 ms (Plomp, 1964). The threshold for temporal discrimination has been referred to as 'temporal auditory acuity' or 'minimum integration time' by Green (1971). To evaluate temporal discrimination, studies have reported of using differentiation of a standard signal and a variable signal to establish the smallest difference that can be perceived of the just noticeable difference using tones, complex signals or silence embedded in a signal (Fitzgibbons & Gordon-Salant, 1994; Fitzgibbons & Gordon-Salant, 1995; Green, 1971; Green, 1973; Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 1994). On the other hand, temporal resolution has been measured by determining the smallest gap embedded within a signal (Keith, 2002; Lister, Roberts, Shackelford, & Rogers, 2006; Musiek et al., 2005a; Shivaprakash, 2003). It has been demonstrated that duration discrimination (DD) / temporal resolution are useful in differentiating the temporal processing abilities of older adults from that of young adults (Fitzgibbons & Gordon-Salant, 1994; Fitzgibbons & Gordon-Salant, 1995; Phillips et al., 1994). In India, information regarding temporal discrimination abilities of normal hearing adults has been provided by Barman (2008). They observed that for the 39 adults studied by them (16 to 26 years), discrimination for anchor stimuli having a duration of 50 ms was 26.79 ms, with the range being 20 to 35 ms (SD = 4.36). On the other hand discrimination for anchor stimuli having a duration of 500 ms was 133.33, with a range of 100 to 200 ms (SD = 36.87 ms).

Further, norms for adults regarding temporal resolution has been given by different authors (Aravindkumar et al., 2012; Mohan & Yathiraj, 2015; Prem, Shankar, & Girish, 2012). It was observed that the norms provided by the different studies did not vary considerably. The study done by (Prem et al.) evaluated the largest number of young adults (N = 70) and they found the mean Gap-In-Noise test (GIN) scores to be 5.64 (SD =1.27).

Temporal integration was described by Shinn (2003) as the summation of neuronal activity over time. Hence, it was also termed as temporal summation. In normal hearing individuals an improvement in threshold was reported to occur with increase in duration up to about 200 to 300. Likewise, a worsening of thresholds was reported to result with decrease in duration due a time-intensity trade-off. Temporal integration has been used by Cranford, Stream, Rye, and Slade (1982) and Cranford (1984) to detect deficits in individuals with cortical lesions, especially in the temporal lobe.

Temporal masking is considered as a shift in threshold of a particular sound when presented either prior to or after another stimulus (Shinn, 2003). Temporal masking is yet another procedure used to identify temporal perceptual difficulties of those with peripheral hearing loss (Zwicker, Schorn, Ashoor, & Prochazka, 1982) as well as identify the perceptual difficulties of older individuals (Gordon-Salant & Fitzgibbons, 1999).

While different temporal components are utilized while processing auditory signals, not all of them are generally used while assessing auditory processing abilities. The temporal based phenomena that are predominantly reported in literature are temporal ordering and temporal resolution. The impact of these temporal components on ageing has been studied by several researchers.

Effect of aging / hearing loss on temporal processing

Difficulty in understanding speech is a common problem reported by older adults. A decline in auditory temporal processing has been considered to account for some of the problems in speech perception. Age-related differences in temporal processing, especially in the presence of noise, have been found to depend on temporal processing abilities (Dreschler & Plomp, 1985; Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 2000; Pichora-Fuller & Souza, 2003; Schneider & Pichora-Fuller, 2001; Snell & Frisina, 2000; Snell, Mapes, Hickman, & Frisina, 2002). The association of temporal processing abilities and its link with speech perception has lead to it being widely researched. It has also been widely researched since temporal processing has been found to be affected in older individuals despite normal peripheral hearing (Abel, Krever, & Alberti, 1990; Parra, Iório, Mizahi, & Baraldi, 2004; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Strouse, Ashmead, Ohde, & Grantham, 1998).

Several studies using psychoacoustic measures have reported age-related declines in auditory temporal processing abilities (Fitzgibbons & Gordon-Salant, 2001; Fitzgibbons & Gordon-Salant, 1994; Fitzgibbons & Gordon-Salant, 1998; Fitzgibbons, Gordon-Salant, & Friedman, 2006; Frisina et al., 2001; He, Horwitz, Dubno, & Mills, 1999; John, Hall, & Kreisman, 2012; Pichora-Fuller, 2003; Snell, 1997; Trainor & Trehub, 1989; Vaidyanath & Yathiraj, 2015). Researches using various psychoacoustic experiments have shown age related declines in *gap detection* (Harris, Eckert, Ahlstrom, & Dubno, 2010; He et al., 1999; John et al., 2012; Phillips et al., 2000; Pichora-Fuller, Schneider, Benson, Hamstra, & Storzer, 2006; Schneider et al., 1994; Snell, 1997; Snell & Frisina, 2000; Snell et al., 2002; Strouse et al., 1998; Vaidyanath & Yathiraj, 2015), *duration discrimination* (Abel et al., 1990; Bergeson, Schneider, & Hamstra, 2001; Gordon-Salant & Fitzgibbons, 1999; Gordon-Salant, Yeni-Komshian, Fitzgibbons, & Barrett, 2006), and *temporal ordering* (Humes & Christopherson, 1991; Trainor & Trehub, 1989).

Among the temporal resolution tests that have been studied, *gap detection threshold* that assesses the ability of an individual to detect small gaps in a continuous auditory stimulus has been the most commonly used measure. In general it has been demonstrated that gap detection thresholds, the smallest gap that can be perceived, have been found to be higher in older adults than that found in younger adults (Harris et al., 2010; He et al., 1999; John et al., 2012; 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). Some of these studies correlating gap detection thresholds and audiometric thresholds failed to obtain significant correlations between the two (Schneider et al., 1994; Snell & Frisina, 2000). Strouse et al. (1998) reported of poorer gap detection thresholds in the elderly subjects despite normal hearing. The authors suggested that age-related factors other than peripheral hearing loss contribute to temporal processing deficits of elderly listeners.

To study the effect of ageing, He et al. (1999) obtained psychometric functions for detection of gaps embedded in noise on a group of older adults (mean age of 70.5 years) and a group of young adults (mean age of 31.9 years). They reported that the gap detection thresholds of the two groups did not significantly differ from each other when the noise burst duration was 100 ms and 400 ms. They also reported an insignificant effect of age when the gaps occurred randomly across the stimulus duration. Additionally, the authors noted that when the gaps occurred randomly at 5% or 95% location of the continuous signal in which it was embedded, older adults performed significantly poorer than the young adults. However, the slope of the psychometric function was reported to be similar for the two groups.

Similarly, to evaluate the effect of ageing, frequency and duration pattern recognition was studied by Parra et al. (2004) on 25 older individuals aged between 60 to 80 years with normal hearing sensitivity. They observed a high variability in responses on frequency and duration pattern recognition despite the participants having no history of central impairment. The 97% confidence interval scores ranged from 23% to 96% and 17% to 98% for duration pattern and frequency pattern respectively. This variability was much larger than what is typically observed in young normal hearing adults in other studies. Thus, it can be noted that the performance of older adults is poorer compared to young adults.

Kolodziejczyk and Szelag (2008) reported poorer temporal order judgment in centenarians (aged 95 to 103 years) than the elderly individuals (aged 65 to 67 years) and younger adults (aged 19 to 25 years). The participants were screened at 250 and 500 Hz to ensure symmetry in hearing. They observed that for monaural temporal judgment the centenarians required longer inter-stimulus-intervals compared to the other two groups. They also reported that the performance on temporal order judgment began to deteriorate after the age of 65 years. This deterioration in performance in the centenarians was ascribed to several reasons that included slower rate of information processing, difference in the strategy used to perform the task as well as their lower education levels. Additionally, gender was also considered a factor affecting performance with males performing better than the females, especially in the group of centenarians. However, no information was provided regarding the actual hearing status of the participants to rule out the confounding effect of hearing loss on age.

The effect of increased complexity of a gap detection task on gap detection thresholds of older adults in comparison to young adults with normal hearing was assessed by Harris et al. (2010). They reported that the gap detection thresholds of the older adults were significantly higher than that of young adults when the gaps were inserted at the beginning and end of the stimuli, than when the gaps were in the centre of a noise segment. They also reported that the gap detection thresholds were higher when the gaps occurred randomly compared to when they occurred at a fixed location. Additionally, increased mental effort was reported when the gaps occurred randomly in the beginning and the end of the stimuli. The increased mental effort was considered to occur due to the increased difficulty in predicting the location of the gap.

Kumar and Sangamanatha (2011) studied temporal processing abilities of 176 individuals across six age groups (20 to 30, 31 to 40, 41 to 50, 51 to 60, 61 to 70, & 71 to 85 years). The temporal processes evaluated included gap detection, duration discrimination, duration pattern and modulation detection. They observed that temporal processing abilities showed a systemic decline with age from the fourth decade of life. The gap detection thresholds of the participants above the age of 70 years was reported to be almost eight times greater than that of the youngest group studied. They observed that the scores on duration discrimination were significantly poorer for individuals above 41 years of age compared to those aged 20 to 30 and 30 to 40 years. In contrast to these findings, the performance on the duration pattern test was reported to deteriorate only after the age of 60 years. The authors reported a differential effect of age on modulation detection thresholds. The age at which deterioration of modulation detection thresholds took place was found to vary depending on the modulation frequency. For higher modulation frequencies the modulation detection thresholds were reported to deteriorate earlier at 40 years compared to lower modulation frequencies that deteriorated after the age of 60 years.

The normative data for GIN obtained by Prem et al. (2012) for listeners aged between 17 to 55 years also highlighted the presence of age related deteriorations. Participants aged 17 to 40 years were found to perform statistically better than those aged 41 to 55 years.

In a recent study, Vaidyanath and Yathiraj (2015) compared the performance of older adults aged 55 to 70 years on GIN with the performance on gap detection test (Shivaprakash, 2003). While the former test made use of randomly occurring gaps, the latter test had gaps that always occurred in the centre of a noise burst. They reported of a significant difference between the gap detection thresholds obtained on the two tests. When compared to the norms of young adults, poorer performance was reported in both the tests of temporal resolution. However, the authors reported that the gap detection thresholds obtained using GIN was much higher compared to that obtained with GDT. This difference in performance was ascribed to the design and the procedure used in the two tests. They recommended the use of GIN that used randomly occurring gaps as it enabled detecting subtle deficits in temporal resolution.

The impact of hearing impairment on temporal resolution has been investigated to gain insight into the perceptual problems of these individuals.   Additionally, the effect of presentation level on temporal resolution of those with hearing impairment has also been evaluated in these studies. Glasberg, Moore, and Bacon (1987) noted that in those with hearing impairment, gap thresholds for band-limited noise were larger than those with normal hearing when evaluated at equal sensation levels. This threshold was found to increase when the absolute threshold of the participants increased. It was however noted that there existed a large variability in the gap thresholds for a given degree of hearing loss. Similarly, Moore and Glasberg (1988) reported that for noise markers, gap thresholds were larger for those with hearing impairment than those with normal hearing when tested at equal SPL. This difference was reported to reduce when the testing was done at equal sensation levels. However, they noted that for sinusoidal markers, although the gap thresholds were similar in ears with normal hearing and ears with hearing impairment when evaluated at equal SPL, they were larger for ears with normal hearing when tested at equal sensation levels. Two reasons were provided to account for the better performance in the impaired ears. One was due to the presence of ringing of auditory filters in the normal hearing ears but reduced in the impaired ears due to broader filters. The other reason was that at equal sensation levels the signals would have been louder in the impaired ears compared to the normal ears. As temporal resolution depended on the loudness of the stimuli, the signal heard louder by the impaired ears was considered to have been perceived better.

Likewise it was observed by Madden and Feth (1992) that temporal resolution was significantly poorer in those with hearing impairment compared to normal hearing young adults when the signals were presented at equal sensation levels as well as at equal sound pressure levels. However, this difference was smaller when the testing was done at equal sound pressure level.

Gordon-Salant and Fitzgibbons (1999) investigated age related differences on several speech and non-speech tests of temporal processing in younger (18 to 40 years) and older adults (65 to 76 years) with and without hearing loss. The non-speech tests included duration discrimination, gap detection and temporal order tasks. Additionally, several speech based tests were also assessed (time compressed speech, speech with reverberation, speech with time compression & reverberation, presented in quiet as well as in the presence of noise). Significant effects of age were observed for both speech and non-speech measures. They however failed to obtain a significant effect of hearing thresholds on these tasks. In a similar manner, Phillips et al. (2000) compared the frequency and temporal resolution in elderly listeners with good and poor word recognition scores. They observed that the gap detection threshold of older listeners with hearing loss was poorer than those with normal hearing but there was no significant difference between gap detection threshold of persons with good and poor word recognition scores.

Similar to earlier studies using GIN, John et al. (2012) found a significant effect of age and hearing loss in a groups of older adults with normal hearing, older adults with hearing loss and young normal hearing individuals. Among the two older adults groups the performance of the group with hearing loss was found to be poorer than those with normal hearing. The authors observed a significant negative correlation between articulation index and the gap detection threshold and a positive correlation between age and gap detection threshold. A higher variance in the gap detection thresholds was observed for the older adult group with hearing loss compared to the other two groups. Using a regression analysis they found that the gap detection thresholds increased by 0.55 ms with every 10 years of age.

Besides temporal resolution, other temporal processing skills such as *duration discrimination* have also been found to be affected with ageing. Abel et al. (1990) evaluated duration discrimination abilities of listeners aged 40 to 60 years with normal hearing as well as with hearing loss and compared their performance with young normal hearing adults. The participants with hearing impairment were grouped based on the degree of loss into those with mild-to-moderate hearing loss and moderate-to-severe hearing loss. In addition to duration discrimination, frequency discrimination and speech perception in quiet and in the presence of noise were evaluated. They reported that the duration differential limens obtained for the older normal hearing group was poorer compared to that of the young listeners. However, hearing loss was reported to not affect duration discrimination abilities as significant differences in performances between the three older adult groups were absent.

The effect of ageing on duration discrimination was demonstrated by Fitzgibbons and Gordon-Salant (1994) who compared the performance of two groups of older adults aged 65 to 76 years with two groups of young adults. Each age group had a group with normal hearing and another with mild-to-moderate sloping hearing loss. A significant effect of age and frequency of the stimuli were reported on duration differential limens while no such significant effect of hearing loss was reported. Similar effects of age on duration discrimination abilities were also reported by Gordon-Salant and Fitzgibbons (1999) for stimuli of varying complexity, and for speech stimuli by Bergeson et al. (2001) and Gordon-Salant et al. (2006).

Temporal ordering or patterning is another temporal processing ability that has been reported to be affected by ageing. Trainor and Trehub (1989) assessed auditory stream segregation using two sound sequences that were distinguishable only when played at a slower rate. They reported poorer performance in older adults aged 63 to 77 years when compared to young adults aged 18 to 25 years in their ability to distinguish tone sequences with contrasting orders. It was also reported that the performance of the older adults did not improve at the slower rates unlike what happened with the young adults.

The effect of complexity on temporal order perception was evaluated by Fitzgibbons and Gordon-Salant (1998) in older individuals aged 65 to 76 years. The stimulus complexity was increased using unidirectional frequency shifts, bidirectional frequency shifts, and random pitch change. They found that the complexity of the task had significant effects on the performance of the older adults on temporal order discrimination and temporal order identification tasks. They also reported a significant correlation between the threshold for temporal order discrimination and the scores obtained on the temporal order identification task.

Deficits in temporal order identification have also been reported for binaural stimulus presentation in addition to monaural stimulus presentation. Strouse et al. (1998) evaluated temporal processing in young adults (mean age = 26.1 years) and older adults (mean age = 70.9 years) with normal hearing. Monaural evaluation was done using gap detection and binaural evaluation using interaural time difference. The older adults had poorer monaural (higher gap detection thresholds) and poorer binaural temporal processing (higher interaural time differences) compared to the young adults. Further, in the young adults the gap detection performance was reported to correlate significantly with performance on the interaural time difference task. Such a correlation was not present in the older adults.

In a similar line, Szymaszek, Szelag, and Sliwowska (2006) assessed temporal order judgments monaurally by presentating stimuli to the two ears separately, as well as binaurally by presenting stimuli to the two ears simultaneously with varying inter-stimulus-intervals. Temporal order thresholds were reported to be significant poorer for the older adults (aged 60 to 69 years) compared to the younger adults (aged 20 to 28 years) for the two different stimuli used by them (clicks & tones). The monaural temporal order judgment was reported to be more difficult compared to binaural. Additionally, an effect of gender was reported with the males performing better compared to the females. The poorer performance of the older adults was attributed to slower processing speed of the brain with age.

From the studies on temporal processing in older adults it is evident that with advance in age, performance on different aspects of temporal processing is affected. This has been reported for temporal resolution, duration discrimination as well as temporal ordering or patterning. The majority of studies have demonstrated that the performance of older adults is poorer when compared to young adults. Further, there existed no consensus regarding the effect of hearing impairment on temporal processing. A few studies reported that duration discrimination was not affected in individuals with hearing impairment. However, the large majority of studies noted that temporal resolution was adversely affected with the presence of hearing loss.

Relationship between temporal processing and speech perception

The importance of temporal cues in speech perception has been demonstrated in several studies (Gordon-Salant & Fitzgibbons, 1993; Liégeois-Chauvel, de Graaf, Laguitton, & Chauvel, 1999; Lisker & Abramson, 1964; Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995; Summerfield, 1982; Tyler, Summerfield, Wood, & Fernandes, 1982). This has been demonstrated in studies that have reported of a relation between temporal processing abilities and speech perception abilities.

The association between temporal processing and speech identification was studied by Dreschler and Plomp (1985) on 21 adults with hearing impairment aged 13 to 20 years. As part of an extensive test battery they evaluated temporal resolution using gap detection as well as forward and backward masking of clicks presented at different time intervals after and before a masking noise respectively. The speech perception measures included vowels, consonants, and sentence identification in quiet and in the presence of noise. They reported a correlation between phoneme perception in noise and forward and backward masking slopes, though it was weak. They also observed that gap detection threshold was important for perception of speech, especially in the presence of noise. From the results they concluded that that poor speech recognition in those with hearing impairment was related to frequency resolving power and temporal resolution.

Snell and Frisina (2000) investigated the effect of age and hearing thresholds on the relationship between temporal processing abilities and word recognition in the presence of noise. They evaluated 40 young listeners aged 17 to 40 years and 40 older listeners aged 61 to 82 years. They measured gap detection thresholds for gaps embedded in noise bursts with low-pass filter cut-off frequencies of 1 and 6 kHz in three background conditions (i.e. no background noise, continuous white noise, & high frequency masker). Additionally, word recognition was measured in the presence of a babble noise. They reported of significantly smaller gap detection thresholds in the younger listeners in all the three background conditions. Also, significantly lower spondee-in-babble thresholds were reported for the younger listeners compared to the older listeners. A significant correlation was reported between the gap thresholds and spondee-in-babble thresholds for only the younger groups, but not for the older adults. Hence, they concluded that in young listeners, temporal processing abilities was related to word recognition in the presence of noise.

Similar to the findings of Dreschler and Plomp (1985) and Snell and Frisina (2000) other researchers have also found a correlation between temporal processing abilities and speech recognition especially in the presence of noise (Phillips et al., 2000; Snell et al., 2002). These studies also demonstrate that significant age-related changes occur in auditory processing throughout adulthood. Age-related changes in temporal acuity were found to begin decades earlier than age-related changes in word recognition.

The importance of temporal cues in good speech recognition was reported by Shannon et al. (1995). They removed spectral information from speech using low-pass filtering thereby preserving temporal and amplitude cues. From consonant, vowel and sentence recognition tests measured on eight normal hearing listeners, they observed that even in conditions where the spectral information was reduced, speech recognition performance was found to be good. They also reported that voicing and manner of articulation perception showed similar perception as these were mainly dependent on temporal envelope information. Based on these findings they concluded that although speech recognition required both spectral and temporal information, in those individuals with spectral resolution difficulties due to hearing loss, temporal cues could be used for speech recognition.

Need for a screening test for temporal processing

From the review of literature it is evident that with advance in age temporal processing difficulties increase. However, information regarding the prevalence of this difficulty in older adults has not been reported. Difficulty in providing this information probably stems from difficulty in obtaining the information due to the lack of tools that are quick yet sensitive to the condition.

In India, it is observed by the Central Statistics Office Ministry of Statistics and Programme Implementation (2011) that there is a steady increase in the number of older adults who are above the age of 60, while there is a decrease in the number of children. The report elaborates that in 1991 those above the age of 60 years accounted for 6.7% of the population, but predicts that it would increase to 10.7% by the year 2021. There is a high likelihood that a large number of these individuals are at-risk for temporal processing problems. Due to the vast population it would be an impossible task to run temporal processing tests on all of them to detect the presence or absence of temporal processing difficulties. The availability of a screening test for temporal processing would enable making referrals for diagnostic tests only for those who need to be tested in detail, thereby reducing the need to conduct diagnostic tests on everyone to detect the presence of the condition. This would enable providing timely intervention in a effective manner, as the screening test would cut down on the time take to detect the presence or absence of the condition, reduce the need for extensive resources as well would be more cost-effective.

Additionally, the availability of a temporal processing screening test would give impetus to research to determine the prevalence of the condition in adults. While information is available regarding the prevalence of acquired hearing loss in adults, which is reported to be high in older adults (Lim & Stephens, 1991; Okhakhu, Okolugbo, & Onyeagwara, 2013), no such information is available regarding auditory processing problems in older adults. In rural India, the prevalence of hearing loss among older adults was estimated to range between 11% to 10% (Goswami et al., 2005; Venkatarao, Ezhil, Jabbar, & Ramkrishnam, 2005). In addition to the hearing loss reported in older adults, difficulty in understanding speech in the presence of noise, disproportionate to their hearing problem, has also been noted (Gordon-Salant, 2005; Souza, Boike, Witherell, & Tremblay, 2007). In those with hearing loss, besides, physiological changes in the inner ear, changes have been noted in the central auditory pathway in older adults (Caspary, Milbrandt, & Helfert, 1995; Willott, 1996). These changes in the central auditory pathway may result in changes in temporal processing abilities of these older adults. The auditory temporal processing deficit in older adults can in turn have an effect on the speech perception skills in quiet and in challenging listening environments.

Further, several studies have reported of older adults not using their hearing aids regularly. These studies noted that 32% to 75% of older adults do not use hearing aids regularly (Chia et al., 2007; Lupsakko, Kautiainen, & Sulkava, 2005; Smeeth et al., 2002; Vuorialho, Karinen, & Sorri, 2006). Reasons given for poor utility of hearing aids include access, high cost and training issues, denial of the presence of hearing impairment and limitations due to technology of the devices (Popelka et al., 1998). Besides these reasons it is also possible that these individuals do not use their hearing aids due to poor benefit on account of the presence of a temporal processing problem. Poor temporal processing in older adults resulting in difficulty in speech perception has been found to have a negative influence on the benefits derived from amplification. Gatehouse (1994) found a significant correlation between temporal resolution abilities and perceived hearing difficulties as well as with aided benefit obtained, especially in the presence of noise. Based on the findings of the study, Gatehouse reported that measures of temporal resolution should be considered as one aspect to assess candidacy for hearing aids. It was recommended that signal processing strategies that help overcome the effects of temporal resolution difficulties need to be used in hearing aids.

Screening tools for auditory processing problems have mainly been developed for children. These screening tools include both questionnaires / checklists (Anderson & Smaldino, 2000; Fisher, 1976; Simpson, 1981; Smoski, Brunt, & Tannahill, 1992; Willeford & Burleigh, 1985; Yathiraj & Mascarenhas, 2003, 2004) as well as screening tests (Cherry, 1992; Domitz & Schow, 2000; Keith, 1994; Keith, 1986; Keith, 2009b; Yathiraj & Maggu, 2012; Yathiraj & Maggu, 2013). However, information regarding screening procedures for adults is sparse. Vaidyanath and Yathiraj (2014) developed a screening checklist titled 'Screening checklists for auditory processing for adults (SCAP-A)' to identify auditory processing deficits in older adults. They compared the two versions of the screening checklist, one to be answered by the target adult and the other to be answered by a family member. Each checklist containing 12 questions aimed to tap auditory separation/closure, auditory integration, temporal ordering, as well as memory and attention related symptom. The results of the 102 participants aged 55 to 75 years and 84 family members indicated that many older individuals faced auditory processing related symptom mainly, auditory separation/closure and memory related ones. A possible reason why temporal based were not detected is because the questionnaire only tapped temporal ordering / patterning, and did not evaluate other aspects of temporal processing. The other temporal based aspects were not tapped primarily due to the difficulty in deriving information them from the participants based on day-to-day activities.

The other tools available for screening auditory processing problems in adults include SCAN-A (Keith, 2008; Keith, 1995), SCAN-3:A (Keith, 2009a) and Multiple Auditory Processing Assessment (Schow, Seikel, Brockett, & Whitaker, 2007). It was reported that SCAN-3 had a sensitivity of 66% and specificity of 74% in adults (Keith, 2009a). In a more recent report (Keith, 2012), SCAN 3:A was noted have a sensitivity of 93% and specificity of 49% when a cut-off score of less than 8 was used. The report however, did not provide information regarding the method used to establish the sensitivity and specificity. Additionally, the screening test did not tap any temporal process, despite difficulty in this process being widely reported in literature. While the sensitivity and specificity is provided for SCAN-A, no such information is available for the screening procedure given by Schow et al. (2007). Further, scores of this procedure is available only on 15 adults aged 21 to 49 years.

Thus, it is evident for the review of literature that there are very few screening tools to assess auditory processing disorder in adults. Hence, there was a need to develop one such tool that can detect processing problems not only in those with normal peripheral hearing, but also in those with hearing impairment. This would enable appropriate diagnosis, which in turn can give direction for suitable audiological management. Studies indicate that temporal processing is frequently affected in older adults and poor temporal processing leads to speech perception problems. Hence, the present study was undertaken to develop and validate a screening tool for assessing temporal processing in adults with and without hearing impairment.

Need for evaluating temporal processing in languages having different temporal cues

Studies indicate a difference in temporal characteristics across languages. One reason for the difference is on account of the difference in the use of aspirated speech sounds. Such differences have been reported in Kannada and Marathi, the former being a Dravidian and the latter being an Indio-Aryan language. Although both language groups use aspirated speech sounds, these class of speech sounds are more commonly used in Indo-Aryan languages such as Marathi (Bhaskararao, 2011; Ramakrishna et al., 1962). The frequency of occurrence of both voiced and unvoiced speech sounds in Marathi were also reported considerably higher compared to Kannada (Ramakrishna et al., 1962). It is well documented that temporal cues one of the major acoustical cues that are used in differentiating voiced and unvoiced speech sounds (Benki, 2001; Liberman, Delattre, & Cooper, 1952; Lisker & Abramson, 1964).

Patil and Rao (2011) have observed that aspiration has an important role in Indian languages. They reported that languages like Marathi have lexicons in which the word meaning differs only because of the differences in aspiration features. Further, Patil and Rao (2013) noted that in Marathi one of the distinguishing properties of aspiration in voiced plosives is duration. Additionally, Rami, Kalinowski, Stuart, and Rastattera (1999) noted that the voice onset time between aspirated and unaspirated unvoiced stops was statically significantly different in Gujarati. They also reported of a resemblance between Gujarati, Marathi and Hindi.

From the review on temporal cues used in Dravidian and Indio-Aryan languages, it can be stated that these cues vary in Kannada and Marathi. There is a likelihood that these variations may influence temporal based auditory test performance. Hence, there is a need to check if differences exist in the temporal abilities of native speakers of different languages. If there is a difference among native speakers of different languages, separate norms are required for persons of different language groups. Hence, besides developing and validating a screening tool for assessing temporal processing in adults with and without hearing impairment, the study also aimed to evaluate whether temporal processing performance varied depending on the native language of individuals.

2. Methods

The investigation was conducted in two phases. The first phase dealt with the development of a screening tool 'Temporal ability screening test'. The second phase included administration of the screening test and a battery of temporal based diagnostic tests. The latter phase of the study was carried out in two different centres located in two different states (Karnataka & Maharashtra) in order to compare the temporal processing abilities of native speakers of regional languages (Kannada & Marathi) having different temporal segmental cues.

Phase I: Development of the 'Temporal Ability Screening Test' (TAST)

The development of TAST involved the rational for the selection of the stimuli, generation of the stimuli for the test, the recording of the instructions in two different languages. Given below are details of the development and a description of the subsections of the test.

Construction of TAST

The 'Temporal Ability Screening Test' (TAST) was constructed to have 3 subsections that evaluated different aspects of temporal processing. The 3 subsections evaluated temporal resolution, temporal discrimination and temporal ordering. The material used in the 3 subsections were akin to that used in the Gap in noise test (GIN), Duration discrimination test (DDT) and Duration pattern test (DPT), respectively. These subsections were selected as they evaluated different aspects of temporal processing. While the GIN subsection was designed to screen for temporal resolution, the other two subsections [duration discrimination subsection (DD) & duration pattern subsection (DP)], screened for temporal discrimination and temporal order respectively.

The construction of three subsections was done using Adobe audition software (Version 3.0). The stimuli were generated in two different tracks, one for testing the left ear and another for testing the right ear of a participant. This was done to enable testing each ear without having to make any changes in the settings once the test commenced. The test commenced with a general instruction regarding the entire test, spoken by a female speaker. Prior to the stimuli used for screening, a 1 kHz calibration tone was provided in order to manipulate the settings to obtain the required output level. Subsequent to the calibration tone, specific instructions for each subsection were provided by the same female speaker. The instructions for each subsection occurred just prior to the practice items, which were followed by the test items for the subsection. The practice items commenced with a recording of a participant demonstrating how to respond to a stimulus, followed by an instruction encouraging the participant being tested to respond. The demonstration was done only for DD and DP and not for GIN. It was not done for GIN as this subsection involved only a pointing response. The test items were presented subsequent to the practice items. A brief instruction alerted the listener before the stimuli were presented to the opposite ear. Initially, the GIN subsection was recorded followed by DD and DP. This order was maintained since the practice items for GIN was distinctly different from the other two subsections. The screening test was designed such that both ears were evaluated before the next subsection was presented. Thus, each subsection had instructions followed by practice items and the test items. Details of the stimuli used, number of practice items, number of test items, presentation level and mode of presentation for each subsection are provided in Table M1.

Recording of TAST

The generation of the stimuli for the screening test was done using Adobe Audition (Version 3) in a sound treated room. All stimuli were generated / recorded using a sampling rate of 44100 Hz and 32 bits quantization. The generated practice and test stimuli were normalized to ensure that the intensity of all the signals (tones & noise) were the same. A 1 kHz calibration tone was generated and normalized to have the same intensity of the practice and test stimuli. The recording of the instructions was done using super cardioid condenser microphone (AKG D7) placed on a stand 6 cm from the mouth of the speaker. The output of the microphone was digitized at 32 bit resolution and a sampling rate of 44100 Hz using USB audio interface (MOTU-Microbook II). The digitized signals were recorded in a computer using Adobe Audition (version 3.0). The recorded instructions were normalised to match the average root mean square power of the test stimuli. The instructions were initially recorded in Indian-English by a female speaker with a neutral Indian-English accent. The instructions were later translated and recorded by native female speakers of Kannada and Marathi, subsequent to the completion of a pilot study using the test with instructions in Indian-English.

Table M1. Details of subsections of TAST

	TAST Subsections		
	Gap In Noise (GIN)	**Duration Discrimination (DD)**	**Duration Pattern (DP)**
Processes tested	Temporal resolution	Temporal discrimination	Temporal ordering
Stimuli	Six spurts of broadband noise of 6 s duration with or without gaps of 7 ms inserted.	Pairs of 1000 Hz tones having durations of 500 ms and 650 ms.	Triads of 1000 Hz tones having short duration of 500 ms (S) and long duration 1000 ms (L), used to form different duration patterns.
Demonstration item	--	1 pair per ear; 1st pair: Tones having different durations (500 ms & 700 ms). 2nd pair: Tones having same duration (500 ms & 500 ms).	1 pattern per ear; 1st pattern : LSL 2nd pattern : SLS
Practise item	1 broad band noise containing 3 gaps per ear; *Gaps in 1st stimulus*: 10 ms, 8 ms, & 10 ms *Gaps in 2nd stimulus*: 8 ms, 10 ms, & 8 ms	1 pair per ear; *1st pair:* Tones having different durations (500 ms & 700 ms) *2nd pair:* Tones having different durations (500 ms & 700 ms)	1 pattern per ear; *1st pattern*: SLS *2nd pattern*: LSL
Number of Test items per ear	5 broadband noise spurts with nine 7 ms gaps; 1 broadband noise spurt with no gap	4 pairs of different durations; 2 pairs with same duration	6 different patterns per ear
Inter stimulus interval	5 s	5 s	6 s
Instructions (Verbatim)	"Listen carefully to the sets of noise.	"You will hear two sounds. They may	"You will hear 3 sounds one after the

	Within the noise you may or may not hear gaps. Please lift your finger each time you hear the gap" (for finger lifting respose or "Listen carefully to the sets of noise. Within the noise you may or may not hear gaps. Please press the response button each time you hear the gap" (for response button).	have same or different durations. Listen carefully and say whether they are same or different durations".	other. The sounds will have long or short durations. Listen carefully and say whether the 3 sounds are long or short, in the order in which you hear them. If the 3 sounds are short, long, and long, you will say short, long, long".
Mode of presentation	Monaural	Monaural	Monaural
Presentation level	40 dB SL	40 dB SL	40 dB SL
Response	Press button / lift finger	Verbal response to indicate whether the 2 stimuli presented are same or different.	Verbally respond the duration pattern of the 3 stimuli presented (Eg Long, short, short for a LSS pattern)
Scoring	'1' for every correct response & '0' for every incorrect response	'1' for every correct response & '0' for every incorrect response	'1' for every correct response & '0' for every incorrect response
Total score per ear	10	6	6

***Description of the subsections of TAST*:**

The Gap-in-noise subsection was designed in line with original GIN test developed by Musiek et al. (2005c). The subsection comprised of two practice items, one for each ear, recorded prior to the test items. Each of the two broadband noise segments used in as practice items had a duration of 6 s and contained 3 gaps. The first practice item contained gaps of 10 ms, 8 ms, and 10 ms, and the second that was played to the opposite ear had gaps of 8 ms, 10 ms, and 8 ms respectively. Subsequent to the practice items, the test contained six, 6 s broadband noise segments for one ear, followed by six for the other ear. The six broadband noise segments for each ear contained nine, 7 ms gaps that were randomly placed within the noise segments. The 7 ms gap duration was selected for the test since it the cut-off value reported to differentiate normal from deviant performance by Musiek et al. (2005c). Further, one of the noise segments in each ear contained no gap. The number of gaps per noise varied from 0 to 3 in each noise segment. The inter-stimulus interval between successive noise tokens was 5 s.

The duration discrimination subsection was generated based on the research reports of Starr et al. (1991) and Barman (2008). Starr et al. (1991) recommended that for duration discrimination of a 1 kHz tone, the fixed tones could either have a duration of 50 ms or 500 ms. However, Barman (2008) noted that the 500 ms tone was easier to discriminate than the 50 ms tone. It was observed that the variable tone had to be at least 54% higher in order for it to be discriminated when the fixed tone was 50 ms. However, for the 500 ms fixed tone, discrimination was possible with less than 50% variability between the two stimuli. Using this finding, pairs of 1000 Hz tones that differed in terms of duration were used for the duration discrimination subsection. The durations of the practice pair of stimuli were 500 ms and 700 ms, while for the test stimuli they were 500 ms and 650 ms. The interval within the pairs of tones was 500 ms and the interval between pairs of tones 5 s. Among the four practice pairs of tones, two had a recorded demonstration of the task, one for each ear. This was followed by another two practice items, one for each ear, for the individual being tested. Two of the pairs of practice items were same and two were different. The recorded instructions and the recorded demonstrations encouraged the individual being tested to indicate whether the stimuli were same or different. Twelve test items, six for each ear, followed the practice items. Of the six test items for each ear, four had pairs that were different and two had pairs that were same. The order in which the same and different pairs were presented were different in the two ears.

The duration pattern subsection was constructed following the ideas of the Duration Pattern Test (Pinheiro & Musiek, 1985). The subsection consisted of instructions, four practice items, two with a verbal demonstration of the responses and two without. The test was constructed such that each ear received both types of practice items. The practice items and the twelve test items were made of 1 kHz tone signals that varied in length. Each item was composed of three tones of short (S) and long (L) durations in various sequences. Six possible three-tone sequence combinations were generated (LLS, LSL, LSS, SLS, SLL, & SSL). For the practice items, the long tone had a duration of 1000 ms and the short tone a duration of 500 ms in order to make the difference more contrastive. For the test items, the duration was maintained similar to that used in the original duration pattern test given by Pinheiro and Musiek (1985), with long tone being 500 ms and the short being 250 ms. The interval within a 3-tone sequence was maintained at 300 ms and between tone patterns, it was 6 s.

The audio recording of TAST was done such that by default the signal was routed to the left ear first and then to the right ear. In order to test the right ear first, the placement of the headphones would have to be reversed such that the right headphone is placed on the left ear and left headphone on the right ear.

Pilot study

The TAST with the instructions in Indian-English was used to conduct a pilot study. The purpose of the pilot study was two-fold. It was done to ensure that the instructions were clear and had no ambiguity. The pilot study also provided information regarding the feasibility of using the stimuli for the screening test. The pilot study was carried out on 10 normally hearing younger adults aged 20 to 30 years and 10 normally hearing older adults aged 50 to 60 year. All the participants were fluent speakers of Indian-English. The stimuli for the TAST, played through a computer, were presented via an audiometer to headphones at 40 dB SL (Ref PTA). The participants were instructed to listen to the instructions and carryout the tasks.

It was observed that all 10 young adults could follow all the instructions, but 4 of the older adults had difficulty following the instructions for the GIN subsection without additional help. Hence, the instructions were altered for the GIN subsection and rerecorded. It was observed that all the young adults were able to respond to the stimuli, however, four of the older adults had difficulty on two of the subtests (3 had difficulty in GIN and DD subsections & 1 had difficulty only in GIN). These four adults were also found to have difficulties on the Screening Checklist for Auditory Processing for Adults (SCAP-A) developed by Vaidyanath and Yathiraj (2014). This screening checklist consisted of 12 questions regarding symptoms of an auditory processing disorder. Hence, no alterations were made to the test stimuli. Further, it was observed that the young adults perform well on all three subsections of TAST with the stimuli presented at 40 dB SL.

Translation of instructions

Translation of instructions to Kannada and Marathi was done once the instruction in Indian-English and the stimuli were finalized. Native speakers of the two languages having good knowledge in English translated the instructions. The translated versions of the instructions were given to 3 native speakers of each languages to translate the instructions back to Indian-English. The reverse translated instructions were compared with the original version. Appropriate corrections were made in the translated instructions such that ambiguous information were eliminated. The recording procedure for the instructions in Kannada and Marathi were similar to that used for the Indian-English instructions. The stimuli used for TAST in the three languages were identical and only differed in the language of the instructions.

Pass / Refer criteria: The pass / refer criteria was based on the data of 60 young adults (30 Kannada speakers & 30 Marathi speakers). From these individuals only those who passed the diagnostic test were included while calculating the cut-off criteria for the corresponding subsection of TAST. The rounded-off value obtained for each subsection after subtracting 1 SD from the mean score value was considered as the cut-off score for each subsection. Table M2 depicts the maximum scores and pass criteria for each of the subtests.

Table M2. Pass criteria for the subtests of TAST

Subsection	**Maximum scores**	**Pass criteria score**
Gap in noise	10	8
Duration discrimination	6	4
Duration pattern	6	4

Phase II: Administration of TAST and Temporal Processing tests

Participants

A total of 260 participants were recruited for phase II of the study and were divided into two groups. Participants in Group I had normal or near normal hearing and Group II had mild-to-moderate hearing loss. Half the participants from each group were native speakers of Kannada, a Dravidian language, and the other half were native Marathi speakers, an Indo-Aryan language. The two languages were chosen as they differ temporally. Although both languages have aspirated speech sounds, they are used less frequently in Kannada when compared to Marathi. It has been well established that the duration of aspirated speech sounds is longer than unaspirated speech sounds.

Group I: Participants with normal / near normal hearing

Group I included 180 participants in the age ranges of 20 to 30 years [Young Adults (YA), 50 to 60 years [Older Adults-a (OAa)], and 60 to 70 years [Older Adults-b (OA-b)]. Each age group had 60 participants, half of whom were native speakers of Kannada and the other half were native speakers of Marathi. In all the subgroups, equal number of males and females were selected for both languages in order to avoid any gender effect between languages. The participants were selected based on the following inclusion criteria:

- The young adults had thresholds less than 25 dB HL from 250 Hz to 8000 Hz and scores of 4 and less on SCAP-A (Vaidyanath & Yathiraj, 2014).
- The older adults who had normal hearing sensitivity at least up to 2 kHz, as recommended by Grose, Poth, and Peters (1994),
- All participants had normal middle ear functioning as determined by immittance evaluation;
- Presence of TEOAEs,
- Speech identification scores of greater than 75% on speech identification tests developed by Yathiraj and Vijayalakshmi (2005) or Vanaja and Singh (2009),
- No report of otological or neurological problems,
- No history of speech and language problems,
- Score of ≥ 24 on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), and

Group II: Participants with mild-to-moderate hearing loss

Forty participants, aged 50 to 60 years [Older Adults-a (OAa)], and 40 participants aged 60 to 70 years [Older Adults-b (OAb)] with symmetrical mild to moderate sensorineural hearing loss were included in Group II. Equal representation of the two language groups was ensured. These participants met the following criteria:

- Sensorineural hearing loss not greater than 50 dB HL,

- Score of ≥ 24 on the Mini Mental State Examination (Folstein et al., 1975),
- No report of otological or neurological problems and
- No history of speech and language problems.

Table M3 provides a summary of the participants included in the study. This includes the normal hearing participants (Groups I) and the participants with hearing impairment (Group II). The age subgroups within each of the above groups are also given.

Table M3. Number of participants with normal hearing (Group 1) and number with hearing impairment (Group II) in each of the age subgroups

Groups	**Group I (Normal Hearing)**		**Group II (Hearing Impaired)**		**Total**
	Kannada	**Marathi**	**Kannada**	**Marathi**	
20 to 30 yrs young adults (YA)	30	30	--	--	60
50 to 60 yrs older adults (OAa)	30	30	20	20	100
60 to 70 yrs older adults (OAb)	30	30	20	20	100
Total	90	90	40	40	260

Instrumentation

Calibrated two-channel diagnostic audiometers (Madsen Astera at Mysore & Madsen OB 922 at Pune) with supra-aural headphones (TDH 39) were used for obtaining air-conduction thresholds, speech recognition threshold, speech identification scores and to administer TAST and other diagnostic tests. The same audiometers with a bone-vibrator (Radioear B 71) were used to obtain bone-conduction thresholds. Calibrated immittance meters (GSI Tympstar, version 2A at Mysore & Amplaid A756 at Pune), with default probe-assembly and contralateral insert earphones, were used to assess middle ear functioning. Diagnostic otoacoustic emission instruments (ILO version 6 at Mysore & Biologic Scoutplus at Pune) were utilised to rule out dysfunction of outer hair cells. The screening test and the diagnostic APD tests were played through a desktop computer, the output of which was routed through the audiometer to headphones. A compact disc with TAST loaded was played through the computer. By default the tests start with the left ear then the right ear follows.

Test environment

All the audiological tests were carried out in well illuminated, air-conditioned, acoustically treated double room set-ups. The ambient noise levels in the room were within specified limits as per American National Standard Institute specifications (ANSI S3.1-1999.). Case history and the questionnaires were administered in quite room, free from distraction.

Procedure for administration of TAST

Procedure for participant selection: Prior to evaluating the participants on the TAST and the diagnostic temporal tests, they were evaluated to ensure that they met the participant selection criteria. They were initially evaluated using two screening tools. The Mini Mental state examination (Folstein, et al., 1975) was administered to rule out cognitive impairment in all the participants. The SCAP-A (Vaidyanath & Yathiraj, 2014) was used to select participants with no symptoms of auditory processing disorder in young adult group.The Kannada and Marathi translated versions of these tests were used. Only those with scores ≥ 24 on the Mini Mental Status Examination were selected. Additionally, they were also required to obtain scores of ≤ 4 on the self-rating version of SCAP-A, which consisted of 12 questions regarding symptoms of auditory processing deficits. Additionally, they were evaluated on a battery of audiological tests to confirm their hearing abilities (pure-tone thresholds, speech reception threshold, speech identification, immittance responses). Those who met the participant selection criteria were recruited for the study.

The newly developed screening test, TAST was played through a computer, the output of which was sent to the audiometer. The participants heard the stimuli via TDH-39 headphones. The stimuli were presented at 40 dB SL. All the participants were administered the newly developed screening test, TAST. Half the participants at both the centres were tested in the left ear first and half were tested in the right ear first to avoid ear effects. As the default settings of TAST initiated testing in the left ear, to testing the right ear first, channel toggle buttons in the audiometers were used. The participants were informed to listen carefully to the recoded test instructions and carryout the tasks. They were informed prior to testing that in case they faced any difficulty in following the recoded instructions, they could indicate that they wanted the test to be stopped by raising their hand. Such individuals were given additional oral instructions.

The time taken to give the initial instructions, place the headphones, run and score the TAST was found to be not more than 12 minutes. This time varied marginally depending on the language of the instructions. The time taken for the Indian-English version used in the pilot study and the Marathi version were similar with it being 11 min 30 s, while it was 12 min for the Kannada version.

Scoring of TAST was done separately for the three subsections for each ear. The scores were given for the test items as given in Table 1M. To prevent any tester bias, the responses on TAST were scored after all the diagnostic tests were administered.

Procedure for administration of the diagnostic tests:

All the participants in Group I and Group II underwent three diagnostic tests to evaluate temporal processing abilities. To assess temporal resolution, GIN (Musiek et al., 2005c) was utilised. DDT (Starr et al., 1991) was administered to test temporal discrimination and DPT (Pinheiro & Musiek, 1985) for temporal patterning/ordering. While the original GIN test was used, the other two tests were reconstructed to have stimuli identical to the original tests. The CD versions of all three tests were played on a computer and were routed monaurally at 40 dB SL (ref. PTA) through the audiometer to headphones. Each ear was tested separately. To avoid an ear effect, half the participants were tested first in the left ear followed by the right ear and vice versa for the remaining half. This was done for each subgroup of participants (age group, hearing impairment & language).

Procedure for administration of Gap-in-noise test

The Gap-in-noise test (GIN) developed by Musiek et al. (2005c) was used to assess the temporal resolution abilities. The CD version of the test was used (with the authors' permission). The test contained a series of 6 s segments of broadband noise. The inter-stimulus interval between successive noise segments was 5 s, during which the individual was required to respond. The duration of the gaps varied from 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 ms. The duration of the gap and the location of the gaps within the noise segments were random. In addition, the number of gaps per 6 s noise segment varied from zero to three. Each gap duration occurred six times in one list, with a list containing up to 36 noise segments with 60 gaps.

From the four equivalent lists available in the test, two were randomly selected for each participant, one for each ear. The participants were asked to indicate the presence of gap by raising their finger as soon as they heard it. The responses of the participants were recorded in scoring sheet recommended in the Musiek et al. (2005c). The number of times each gap was identified correctly was noted by the tester. The minimum duration of gap that a person could detect at least 4 out of the 6 times that it was presented was considered as the gap detection threshold. An individual was considered to have a temporal resolution problem if they obtained scores greater than 5.6 ms, based on the criterion recommended by Prem et al. (2012).

Procedure for administration of Duration Discrimination test

The duration discrimination test was used to assess temporal discrimination abilities. A procedure similar to that recommended by Starr et al. (1991) was used. Pairs of 1 kHz tone, with varying duration, were presented. Within each pair, one served as an anchor tone and the other as a variable tone. In the current study, the participants were tested with a 500 ms anchor tone and the variable tone increased in 50 ms steps. This duration was selected instead of 50 ms to prevent false positives since temporal integration was reported to be better with longer duration signals (Barman, 2008). Initially, the participants were tested with four practice items, two being same and two being different (500-700, 500-500, 700-700 & 500-700 ms). The practice items were presented to one ear only. For those with a hearing impairment, it was presented to the better ear. Following the practice, the participants were evaluated with the 11 test items. The participants were instructed in their native languages to indicate whether the stimuli heard were 'same' or 'different' in duration. The test commenced with larger differences between the anchor and variable tones, and the latter was gradually decreased to determine the smallest difference that could be discriminated. The minimum difference that an individual could discriminate 2 out of 3 times was considered as the discrimination threshold. The lower cut-off criterion (200 ms) given by Barman (2008) was used to classify a person as having problem in duration discrimination. Barman reported that duration discrimination of normal hearing adults ranged between 200 ms and 300 ms.

Procedure of administration of Duration Pattern test

The Duration Pattern Test (DPT) developed by Pinheiro and Musiek (1985) was reconstructed and utilized to determine temporal resolution abilities. The test was composed of three 1000 Hz tones having an inter-tone interval of 300 ms. The short tone (S) had a duration of 250 ms and the long tone (L) had a duration of 500 ms. Six possible combinations of three-tone sequences (LLS, LSL, LSS, SLS, SLL, and SSL) were used having a 6 s inter-pattern interval. Initially, six different patterns were presented as practice items to one ear (the better ear for those with hearing impairment). Each ear was then tested with 30 test items. The participants were instructed to respond verbally, indicating the pattern heard by them. Each ear was scored separately. Every correct response was given a score of 1 and an incorrect response was given a score of zero. The lowest of the scores (24 to out of 30 stimuli) reported by Mohan and Yathiraj (2015) for normal hearing adults was used to classify the participant as having problems in temporal ordering.

A blind approach was followed while scoring TAST and the diagnostic tests. The scoring for the screening and diagnostic tests were done at different times to avoid tester bias. The tester was not aware whether a participant had passed or was referred on the screening test when the diagnostic tests were administered.

Test-retest evaluation

To check the reliability of TAST, 10% of the normal hearing population (N = 18) were tested once again 3 months after the initial evaluation. Equal number of participants were tested from the 3 age groups (I-OAa, I-OAb, & I-YA), with half of them in each age group being native speakers of Kannada and half native speakers of Marathi. The group with hearing impairment were not revaluated to avoid variations in their hearing levels contaminating the test results.

Statistical Analyses:

Descriptive statistic as well as inferential statistics were carried out using SPSS (Version 17) software. The analyses were done in two parts. Part-I of the analyses were done to determine the difference between the two language groups, the three age groups and within each age group the difference between those with and without hearing impairment. Part-II of the analyses involved obtaining the relation between the screening and the diagnostic procedures.

3. Results

The data obtained from the participants were analysed using SPSS (Version 17) to obtain the influence of the native language of the participants (Kannada & Marathi) as well as determine the relation between the subsections of TAST and the corresponding diagnostic tests. To establish the influence of the native language on the diagnostic temporal processing tests the data of 60 young adults were analysed to determine the following: difference in performance between the Kannada speakers and Marathi speakers for each of the diagnostic tests; difference in performance between males and females; and difference in performance of the two ears (left & right ears). The differences between the two language groups were analysed using ANOVA and MANOVA after carrying out a Shapiro-Wilk test of normalcy.

In addition, the following aspects of TAST were studied on the 520 ears of 260 individuals: the pass / refer findings of TAST; the pass / fail findings of the diagnostic tests; the relationship between TAST and the diagnostic tests; sensitivity and specificity of subsections of TAST; cut-off criterion for referral; and the test-retest reliability of TAST. Pearson's product moment correlation coefficient was used to find the correlation between TAST and the diagnostic tests. The sensitivity and specificity was established using a Chi square test. Kappa measure of agreement was used to find the cut-off score in order decide on the pass/refer criteria of TAST. The reliability was calculated using Pearson's product moment correlation. These test results are given under the following sub-headings:

1. Difference in temporal processing among Kannada and Marathi speakers
    1.1 Effect of native language (Marathi & Kannada) on temporal processing abilities [carried out on normal hearing young adults (Group 1YA)]
    1.2 Effect of age and gender on temporal processing abilities [carried out on normal hearing young adults (Group 1YA); normal hearing older adults aged 50 to 60 years (Group 1 OAa); and normal hearing older adults aged 60 to 70 years (Group 1 OAb)]
    1.3 Effect of hearing loss on temporal processing abilities [comparison of Group I 50 to 60 year older adults (OAa) and Group I 60 to 70 year older adults (OAb) with Group II 50 to 60 years older adults (OAa) and Group II 60 to 70 years older adults (OAb)]

2. Relation between subsections of TAST and the corresponding diagnostic (carried out on 520 ears of 260 individuals) was calculated to determine the following:

   2.1 Pass / Refer findings of TAST

   2,2 Pass / Fail findings of the Diagnostic tests

   2.3 Relationship between TAST scores and the diagnostic test scores

   2.4 Sensitivity and specificity of the subsections of TAST

   2.5 Cut-off criterion for referral for TAST

1. Difference in temporal processing among Kannada and Marathi speakers

Prior to analysing the data of the 260 participants to obtain information regarding the influence of native language, age, gender and hearing loss on temporal processing abilities, a box plot was obtained to check for the presence of outliers / extremes. It was noted that 4 participants obtained extreme scores. Further, a normality tests was carried out using Shapiro-Wilk test of normalcy after removing the four extreme data points. The Shapiro-Wilk test showed that the data met criteria for normalcy after removal of extremes. Hence, further analyses were carried out using parametric statistics.

1.1 Effect of native language (Marathi & Kannada) on temporal processing abilities

To determine the effect of language on the temporal processing abilities, the performance of the young adults (Group I-YA) from the two language groups (Kannada & Marathi) were compared on the three temporal based diagnostic tests (GIN, DD, & DPT). The data of the older adults were not considered to avoid the compounding effect of aging and hearing loss. Tables R1, R2 and R3 show the mean and standard deviation for all the parameters for GIN, DD and DPT respectively.

From the tables (R1, R2 & R3) and from Figure R1 it can be observed that individuals in the two language groups obtained similar scores for the three GIN measures (GIN threshold; total number of gaps identified; & ratio of number of gaps identified to number of gaps presented) and duration pattern test. However, the duration discrimination threshold was higher for the native Marathi speakers in comparison to native Kannada speakers. Further, it was noted that all the three tests showed very little variations across ears and gender.

To confirm whether any significant difference occurred between the two language groups, a repeated measure ANOVA was carried out with ear as within subject variable and gender as well as language group as between subject variables (Table R.4). The repeated measure ANOVA indicated that there was no main effect of ear or gender on any of the parameters, as can be observed from the table. However, there was a significant effect of native language on the duration discrimination threshold. Hence, for further analyses, the data of the Kannada and Marathi speakers were combined for values obtained for GIN and DPT, whereas the thresholds obtained for DD were analysed separately for the two language groups.

Table R1: Mean values and standard deviation in parenthesis for various parameters of GIN test for three age groups.

Groups	**Language**	**Kannada**				**Marathi**			
	Gender	**Male**		**Female**		**Male**		**Female**	
	Ear	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
I-YA	**GIN threshold**	4.73 (0.70)	4.86 (0.83)	4.60 (0.63)	4.92 (0.86)	5.83 (0.65)	4.92 (0.86)	4.69 (0.85)	4.76 (1.01)
	Total no. of gaps identified	44.26 (3.49)	43.86 (4.82)	44. 53 (3.33)	40.80 (10.29)	43.07 (4.55)	43.15 (4.29)	44.92 (4.62)	44.76 (4.95)
	No. of gaps identified Vs No. of gaps presented	0.73 (0.05)	0.73 (0.08)	0.74 (0.05)	0.67 (0.17)	0.71 (0.07)	0.72 (0.08)	0.74 (0.07)	0.74 (0.08)
I-OAa	**GIN threshold**	6.80 (1.26)	7.26 (1.33)	6.46 (0.99)	7.06 (1.27)	6.86 (2.13)	6.60 (1.80)	6.86 (2.97)	6.93 (2.46)
	Total no. of gaps identified	33.26 (3.95)	32.00 (3.62)	34.13 (2.82)	32.40 (3.39)	35.26 (7.43)	36.13 (5.81)	34.73 (8.62)	35.20 (8.65)
	No. of gaps identified : No. of gaps presented	0.55 (0.06)	0.53 (0.06)	0.56 (0.04)	0.54 (0.05)	0.58 (0.12)	0.59 (0.09)	0.57 (0.14)	0.58 (0.14)

I-OAb	**GIN Threshold**	8.93 (1.48)	9.46 (1.40)	8.66 (1.44)	9.20 (1.26)	7.20 (2.51)	7.00 (2.26)	7.46 (3.31)	7.33 (2.52)
	Total no. of gaps identified	28.66 (4.70)	26.93 (4.04)	28.93 (4.80)	28.26 (4.63)	32.93 (6.06)	32.86 (7.05)	33.00 (8.63)	32.80 (8.67)
	No. of gaps identified : No. of gaps presented	0.47 (0.07)	0.44 (0.06)	0.48 (0.07)	0.47 (0.07)	0.54 (0.10)	0.54 (0.11)	0.54 (0.14)	0.54 (0.14)
Group II-OAa	**GIN Threshold**	9.45 (2.01)	8.90 (1.86)	7.77 (1.56)	7.33 (1.14)	8.66 (2.23)	8.00 (1.14)	8.00 (2.86)	7.90 (2.23)
	Total no. of gaps identified	26.18 (5.09)	26.63 (5.22)	29.88 (3.40)	30.44 (3.00)	28.11 (5.68)	28.77 (5.26)	29.50 (6.45)	30.60 (7.16)
	No. of gaps identified : No. of gaps presented	0.43 (0.08)	0.44 (0.08)	0.49 (0.05)	0.50 (0.05)	0.46 (0.09)	0.47 (0.08)	0.48 (0.10)	0.50 (0.11)
Group II-OAb	**GIN Threshold**	11.90 (2.46)	12.40 (2.36)	11.10 (2.13)	10.20 (1.75)	11.33 (2.57)	12.16 (3.37)	10.00 (1.78)	10.33 (1.50)
	Total no. of gaps identified	19.50 (5.89)	17.80 (6.19)	22.60 (6.27)	24.80 (5.32)	19.91 (6.63)	21.00 (7.49)	24.16 (5.03)	24.16 (5.19)
	Ratio	0.32 (0.09)	0.29 (0.10)	0.37 (0.10)	0.41 (0.08)	0.32 (0.11)	0.34 (0.12)	0.40 (0.08)	0.40 (0.08)

Note. Gp I = Group with normal hearing; Gp II = Group with hearing impairment
YA = Young adults; OAa = Older adults (50 to 60 years); OAb = Older adults (60 to 70 years)

Table R2: Mean values and standard deviation in parenthesis for DD threshold for three age groups.

Language	**Kannada**				**Marathi**			
Gender	**Male**		**Female**		**Male**		**Female**	
Ear	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Group I-YA	130.00 (25.35)	123.33 (25.81)	123.33 (37.16)	143.33 (25.81)	200.00 (91.28)	188.46 (82.04)	153.84 (43.11)	165.38 (47.36)
Group I-OAa	160.00 (33.80)	180.00 (64.91)	190.00 (50.70)	196.66 (66.72)	216.66 (69.86)	210.00 (63.24)	236.66 (83.38)	240.00 (82.80)

Group I-OAb	213.33 (74.32)	203.33 (63.99)	190.00 (43.09)	210.00 (43.09)	223.33 (90.36)	223.33 (97.95)	200.00 (56.69)	213.33 (71.87)
Group II-OAa	195.45 (65.01)	200.00 (50.00)	172.22 (36.32)	172.22 (44.09)	211.11 (65.08)	211.11 (65.08)	255.00 (92.64)	260.00 (102.11)
Group II-OAb	270.00 (78.88)	260.00 (69.92)	230.00 (85.63)	240.00 (84.32)	229.16 (83.82)	237.50 (95.64)	300.00 (77.45)	325.00 (82.15)

Note. Standard deviation values are mentioned in parenthesis.
Gp I = Group with normal hearing; Gp II = Group with hearing impairment
YA = Young adults; OAa = Older adults (50 to 60 years); OAb = Older adults (60 to 70 years)

Table R3: Mean values and standard deviation in parenthesis for DPT scores for three age groups.

Language	**Kannada**				**Marathi**			
Gender	**Male**		**Female**		**Male**		**Female**	
Ear	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Group I-YA	27.66 (2.35)	27.86 (1.64)	27.60 (2.26)	28.06 (1.27)	27.15 (1.99)	26.76 (2.04)	28.07 (1.44)	27.92 (1.70)
Group I-OAa	24.00 (1.64)	25.26 (1.94)	24.93 (2.28)	25.06 (2.54)	25.60 (2.72)	25.53 (2.58)	25.20 (2.59)	25.06 (3.08)
Group I-OAb	23.13 (2.69)	23.73 (3.57)	22.06 (3.78)	22.73 (3.55)	23.20 (3.91)	23.13 (4.43)	24.33 (4.27)	24.40 (3.77)
Group II-OAa	23.18 (2.44)	23.18 (2.35)	22.44 (4.33)	22.77 (3.99)	19.88 (6.39)	19.33 (6.12)	23.90 (3.98)	22.80 (4.13)
Group II-OAb	19.60 (3.62)	20.00 (3.62)	21.30 (3.65)	22.00 (3.74)	19.50 (7.48)	20.16 (7.19)	23.83 (3.86)	21.50 (6.09)

Note. Gp I = Group with normal hearing; Gp II = Group with hearing impairment
YA = Young adults; OAa = Older adults (50 to 60 years); OAb = Older adults (60 to 70 years)

Table R4: Results of repeated measure ANOVA for Group I – Young adults.

		df	F value					
			Ear	**Gender**	**Language**	**Ear * Language**	**Ear* Gender**	**Ear*language* gender**
GIN	**Threshold**	1, 52	0.12	3.29	1.92	1.27	0.83	1.36
	Total no. of gaps identified	1, 52	1.03	0.02	0.34	0.96	0.74	0.56
	No. of gaps identified : No. of gaps presented	1, 52	0.97	0.008	0.21	1.07	0.87	0.50
DPT	**DPT score**	1, 52	0.03	1.37	0.45	2.89	0.43	0.02
DD	**Threshold**	1, 52	0.53	1.14	12.90**	0.54	7.48**	0.04

Note. df = degree of freedom; ** = $p < 0.01$; * = $p < 0.05$
GIN = Gap-in-noise; DPT = Duration pattern test; DD = Duration discrimination

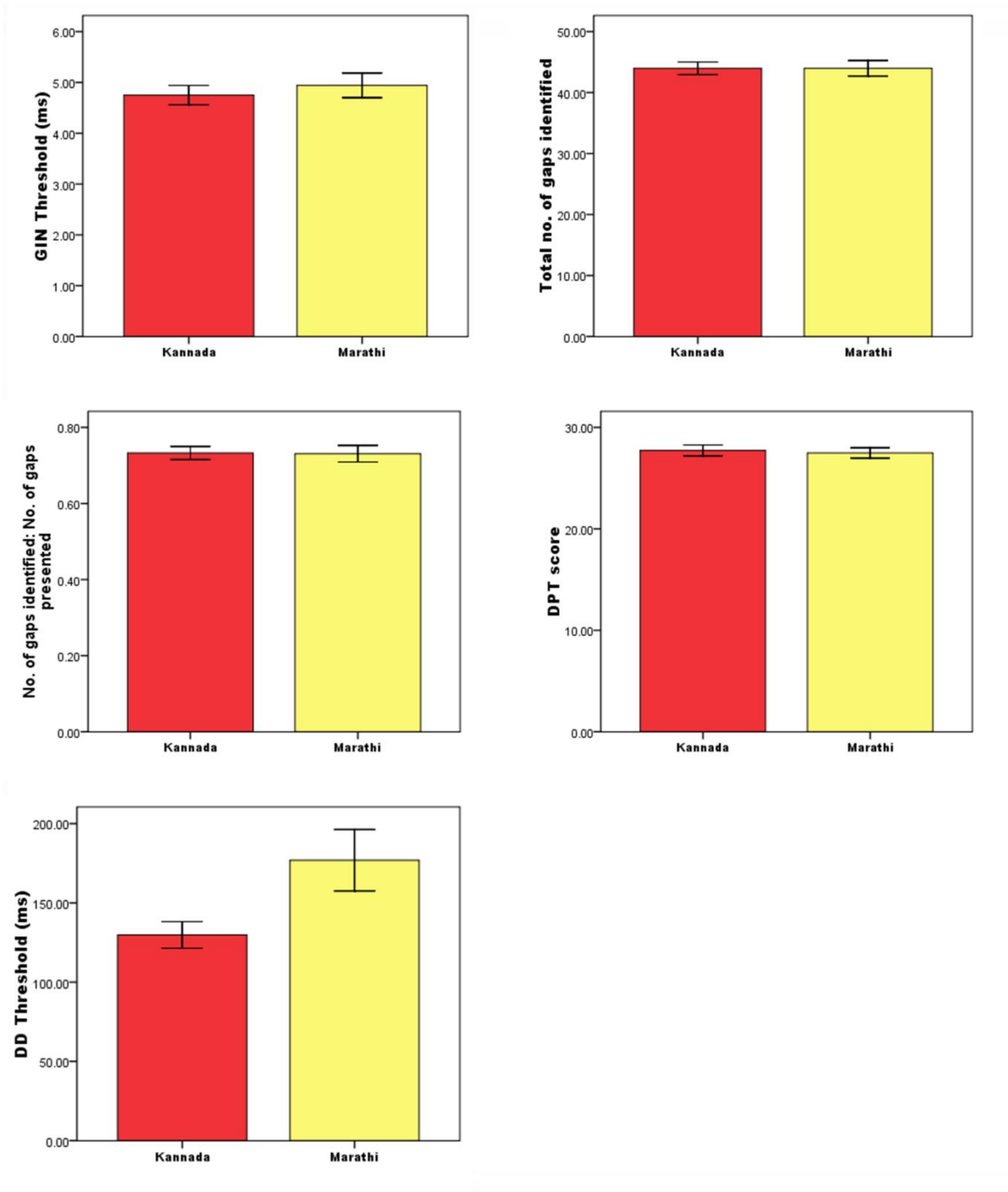


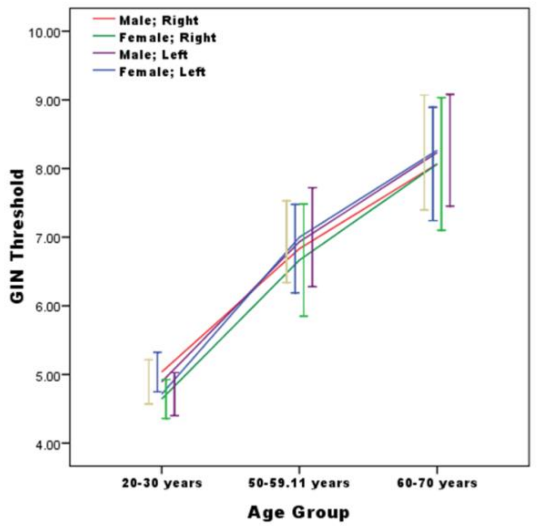
Figure R1. Mean and standard deviation (whiskers) of scores of native speaker of Kannada and Marathi for GIN, Duration Pattern Test, and Duration Discrimination Threshold.

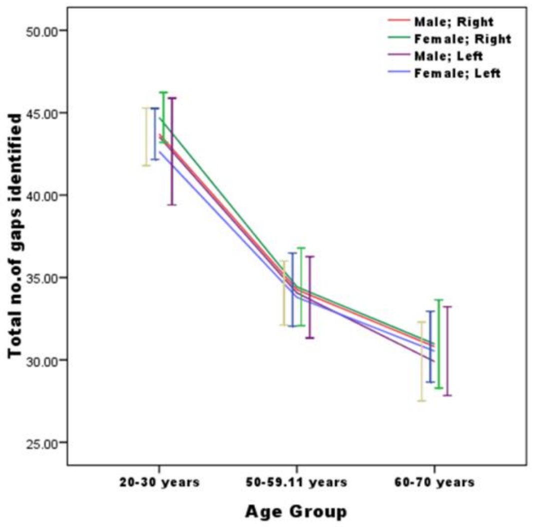
1.2 Effect of age and gender on temporal processing abilities

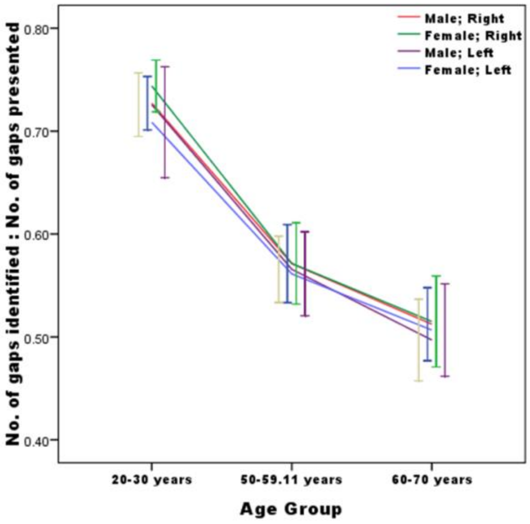
The effect of age on temporal processing was investigated by comparing the results obtained on the temporal processing tests (GIN, DPT, & DD) across the three age groups having normal hearing [20 to 30 years (Group I-YA), 50 to 59;11 years (Group I-OAa), & 60 to 70 years (Group I-OAb)]. An inspection of the mean and standard deviation shown in Figure R2 indicated that in general the temporal abilities decreased with increase in age. The only exception to this trend was the duration discrimination thresholds obtained from the normal hearing female Marathi speakers. As can be observed from Table R2, the female Marathi participants in Group I-OAb (60 to 70 years) had better duration discrimination thresholds (lower threshold) than the participants in Group I-OAa (50 to 60 years).

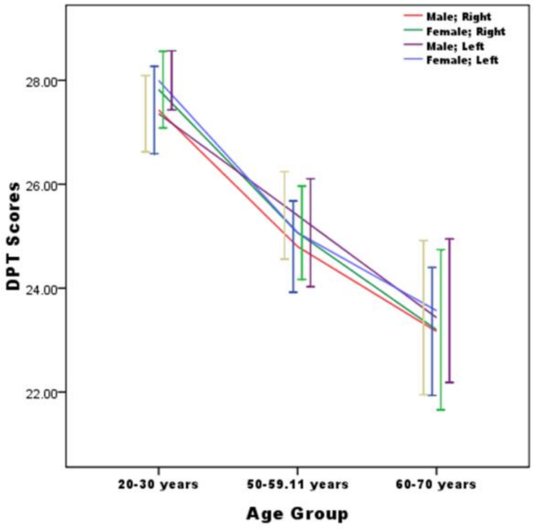
In order to determine the effect of age statistically, MANOVA was performed for the GIN measures (GIN threshold, total number of gaps identified, & ratio of total number of gaps identified to total number of gaps presented) and DPT scores. GIN measures and DPT scores served as dependent variables whereas the three age groups (Group I- YA, Group I-OAa, & Group I-OAb) and gender were considered as independent variables. The results of MANOVA (Table R5) revealed a significant main effect of age for all the measures for GIN as well as DPT. A post hoc analysis with Bonferroni correction showed that there was a significant difference between age groups ($p < 0.01$) for all the measures of GIN as well as DPT. However, there was no significant effect of gender and there was no interactional effect between age and gender.

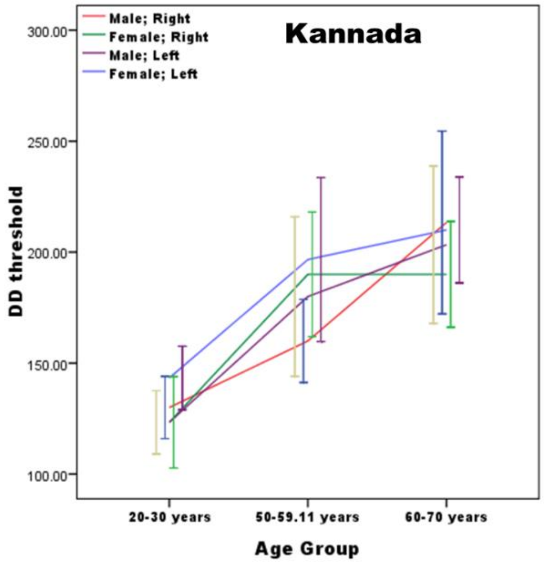
The duration discrimination threshold was analyzed using MANOVA separately for the data obtained from the Kannada and Marathi speakers. There was a significant main effect of age on duration discrimination threshold for native speakers of both the languages. A pair-wise comparison with Bonferroni correction indicated that the duration discrimination threshold in the Kannada speakers was significant difference between Group I-YA and Group I-OAa as well as Group I-YA and Group I-OAb ($p < 0.01$), with it being better in the younger group. On the other hand, for the Marathi speakers the post hoc analysis with Bonferroni correction showed that only Group I-YA obtained significantly better duration discrimination thresholds compared to Group I-OAb ($p < 0.05$). There was no significant main effect of gender and no significant interaction between age and gender on duration discrimination threshold of both Kannada and Marathi speakers.


Male; Right
Female; Right
Male; Left
Female; Left
GIN Threshold
10.00
9.00
8.00
7.00
6.00
5.00
4.00
20-30 years
50-59.11 years
60-70 years
Age Group


Male; Right
Female; Right
Male; Left
Female; Left
Total no.of gaps identified
50.00
45.00
40.00
35.00
30.00
25.00
20-30 years
50-59.11 years
60-70 years
Age Group


Male; Right
Female; Right
Male; Left
Female; Left
No. of gaps identified : No. of gaps presented
0.80
0.70
0.60
0.50
0.40
20-30 years
50-59.11 years
60-70 years
Age Group


Male; Right
Female; Right
Male; Left
Female; Left
DPT Scores
28.00
26.00
24.00
22.00
20-30 years
50-59.11 years
60-70 years
Age Group


Kannada
Male; Right
Female; Right
Male; Left
Female; Left
DD threshold
300.00
250.00
200.00
150.00
100.00
20-30 years
50-59.11 years
60-70 years
Age Group

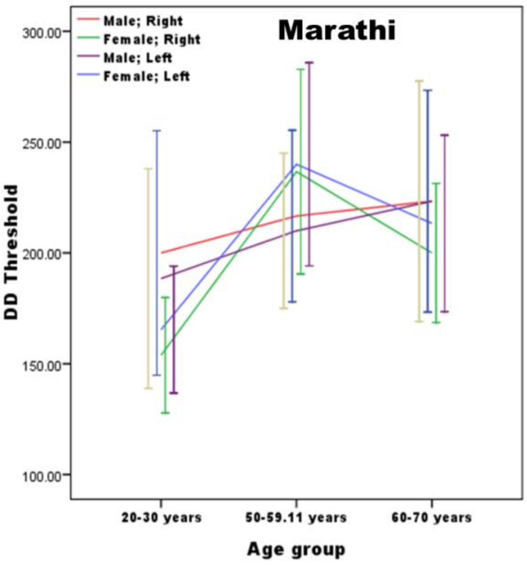

Marathi
Male; Right
Female; Right
Male; Left
Female; Left
DD Threshold
300.00
250.00
200.00
150.00
100.00
20-30 years
50-59.11 years
60-70 years
Age group

Figure R2.: Effect of age in those with normal hearing for three measures of GIN Duration Pattern Test, and Duration Discrimination Threshold

Table R5: Results of MANOVA investigating the effect of age and gender

			Right ear		**Left ear**	
			df	**F value**	**df**	**F value**
GIN	**Threshold**	**Age**	2,170	43.80**	2,170	85.33**
		Gender	1,170	0.44	1,170	0.27
		Age x Gender	2,170	0.16	2,170	0.08
	Total no. of gaps identified	**Age**	2,170	84.78**	2,170	59.28**
		Gender	1,170	0.21	1,170	0.01
		Age x Gender	2,170	0.10	2,170	0.20
	No. of gaps identified : No. of gaps presented	**Age**	2,170	59.65**	2,170	60.05**
		Gender	1,170	0.03	1,170	0.05
		Age x Gender	2,170	0.12	2,170	0.22
DD	**Threshold (Marathi speakers)**	**Age**	2, 80	3.19*	2, 80	3.17*
		Gender	1, 80	1.04	1, 80	0.004
		Age x Gender	2, 80	1.43	2, 80	0.94
	Threshold (Kannada speakers)	**Age**	2, 84	19.83**	2, 84	16.43**
		Gender	1, 84	0.000	1, 84	1.76
		Age x Gender	2, 84	2.55	2, 84	0.13
DPT	**DPT score**	**Age**	2,170	35.97**	2,170	31.34**
		Gender	1,170	0.29	1,170	0.11
		Age x Gender	2,170	0.06	2,170	0.42

Note. df = degree of freedom; ** = $p < 0.01$; * = $p < 0.05$

GIN = Gap-in-noise; DD = Duration discrimination; DPT = Duration pattern test

1.3 Effect of hearing loss on temporal processing abilities

Figure R3 shows the comparison of mean scores for different measures of temporal processing between persons with normal hearing from Group 1 [N = 60 (OAa) & 60 (OAb)] and those with hearing loss from Group II [N = 40 (OAa) & 40 (OAb)], with gender and ear data combined. In general, the older adults with hearing loss tended to perform poorer than age matched normal hearing counterparts.

The effect of hearing loss was studied separately for each of the two older groups by comparing those with hearing loss (Group II-OAa & Group II-OAb) with those without hearing loss (Group I-OAa & Group I-OAb). Independent sample t-tests were carried out to check if there was a significant difference in performance of participants in Group I-OAa and Group II-OAa as well as Group I-OAb and Group II-OAb. As shown in Table R6, a significant effect of hearing loss was observed for all the parameters of GIN as well as DPT in both the age groups. From Tables R1 and R3 it is clear that the normal hearing group (Group I) outperformed those with hearing impairment (Group II). This was evident in both age groups [50 to 60 (OAa) & 60 to 70 (OAb)]. The duration discrimination threshold obtained from native Kannada and Marathi speakers showed no significant effect of hearing loss for Groups I-OAa and II-OAa, the younger of the two older group. However, the oldest participants, Groups I-OAb and II-OAb, showed a significant effect of hearing loss for duration discrimination threshold. This was true for the native Kannada as well as Marathi speakers.

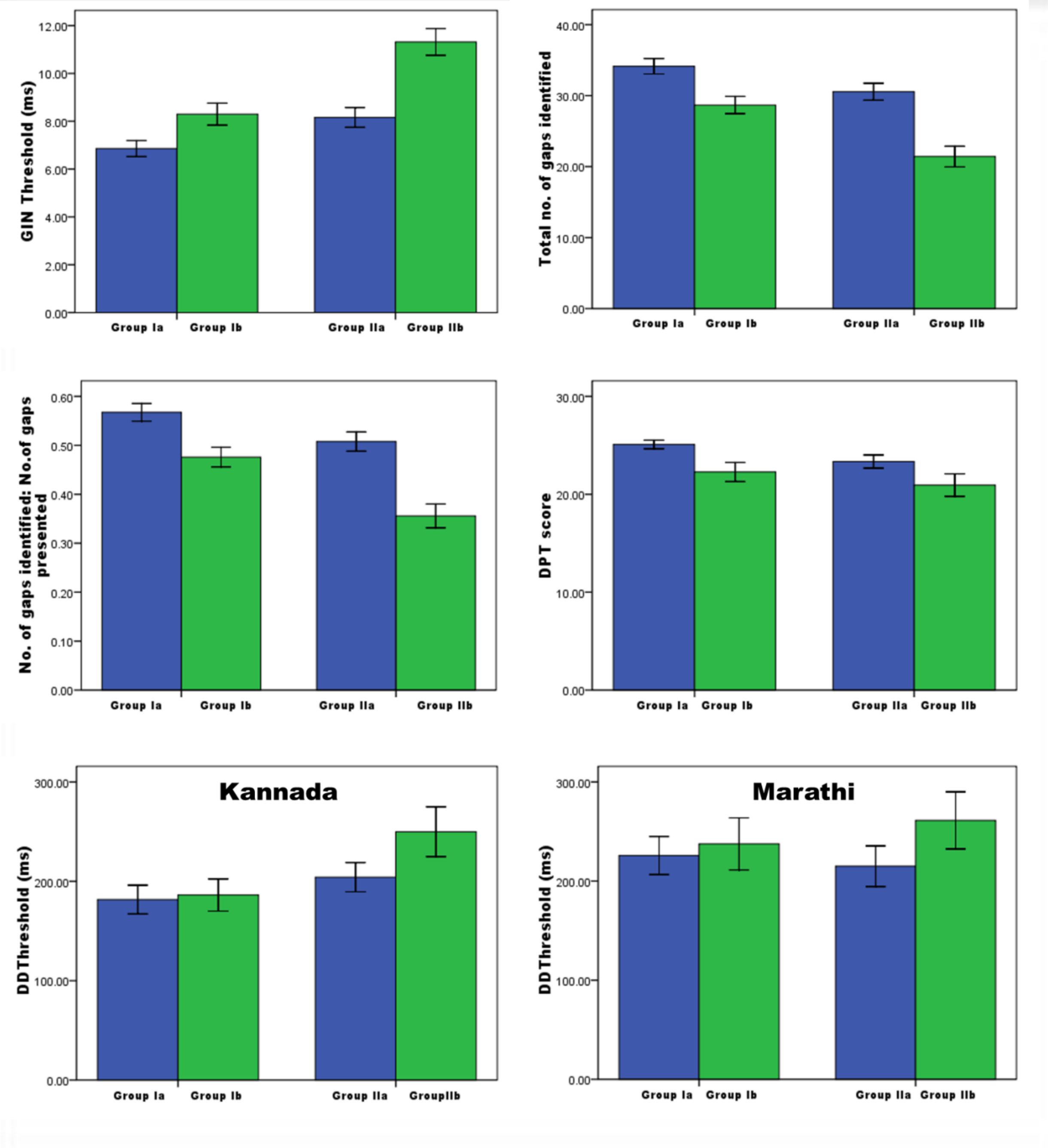


Figure R3. Mean and standard deviation (whiskers) of data obtained from person with normal hearing and those with hearing loss

Table R6: Results of Independent sample t-test comparing the normal hearing group (Group I) with the group with hearing impairment (Group II).

Parameters		**Group I-OAa & II-OAa**		**Group I-OAb & II-OAb**	
		df	**t value**	**df**	**t value**
GIN	Threshold	196	5.12**	196	9.16**
	Total no. of gaps identified	196	6.54**	196	9.56**
	No. of gaps identified : No. of gaps presented	196	6.55**	196	9.59**
DD	Threshold Kannada	98	0.41	98	3.38**
	Threshold Marathi	98	0.73	98	2.70**
DPT	DPT score	198	5.80**	198	3.81**

Note. df = degree of freedom. ** = $p < 0.01$; * = $p < 0.05$
GIN = Gap-in-noise; DD = Duration discrimination; DPT = Duration pattern test
Gp I = Group with normal hearing; Gp II = Group with hearing impairment
OAa = Older adults (50 to 60 years); OAb = Older adults (60 to 70 years)

2. Relation between subsections of TAST and the corresponding diagnostic tests

Prior to establishing the relation between TAST and the corresponding diagnostic tests, the data were analysed to obtain information regarding the pass / refer findings of TAST as well as the pass / fail findings of the diagnostic tests. Besides evaluating the relation between TAST and the diagnostic tests, the following were also determined: the sensitivity and specificity of subsections of TAST, the cut-off criterion for referral for TAST and the test-retest reliability of TAST. The data of all the participant were pooled for these analyses. This was done as there were no significant different between the males and females as well as the two ears. Additionally, the majority of the temporal based diagnostic tests did not differ in the two language groups. The data of those from different age groups and those having different peripheral hearing abilities were combined so as to prevent having skewed data that is known to affect statistical analyses. However, the data of the two hearing ability groups (Group 1 & Groups 2) and the age subgroups (YA, OAa, OAb) are also provided.

2.1 Pass / Refer findings of TAST

Out of the 520 ears of 260 individuals evaluated on TAST, it was found that 334 ears were referred on one or more subsections of TAST and 186 ears passed all the subsections. Figure R4 illustrates the number of ears that were referred on each subsection or combination of subsections. Each ear is represented only once in the figure.

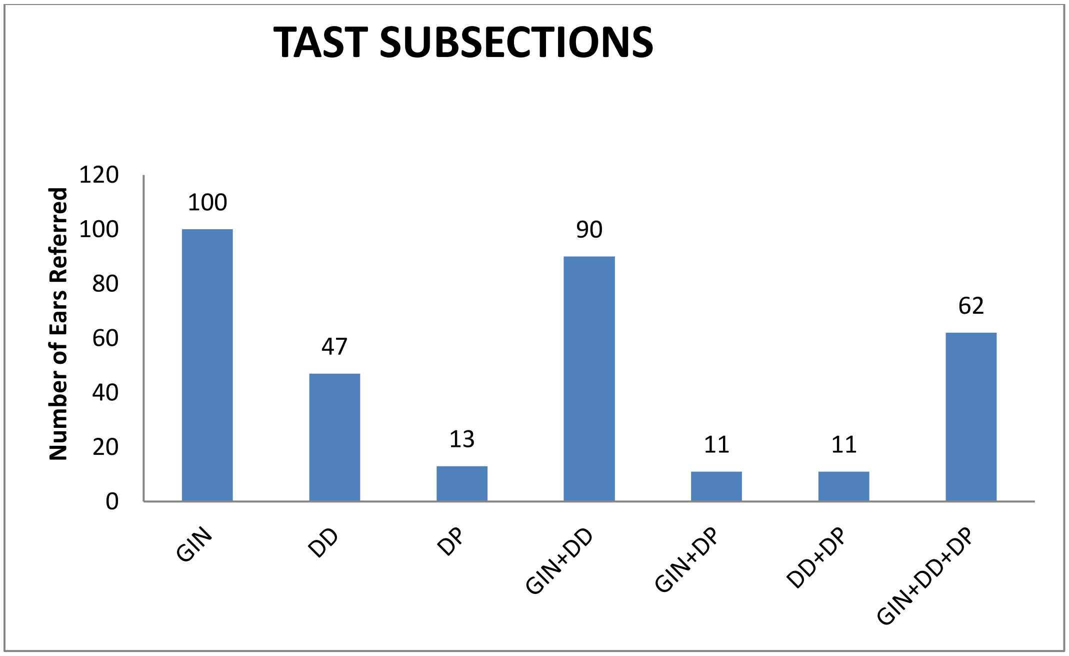


Figure R4: Distribution of 334 ears referred on one subsection or combination of subsections (ears that are referred on more than one subsection are represented only once).

Among the 520 ears tested, 19.23% (100 ears) were referred only on the GIN subsection, 9.03% (47 ears) only on the DD subsection and 2.5% (13 ears) referred only on the DP subsection. The combination of subsections that had the maximum number of ears referred was GIN and DD (90 ears; 17.3%).

Figure R5 represents the number of ears that were referred on 1 subsection and combination of subsections. The value given represents the number of times an ear was referred on the various subsections of TAST. The data of the TAST from 520 ears revealed that 63 ears (12.11%) were affected in all the three subsections. From Figures R4 and R5 it can be observed that maximum number of ears failed the GIN subsection. Further, the combination of the GIN and DD subsections detected a larger number of ears at-risk for temporal processing problems among the combination of subsections.

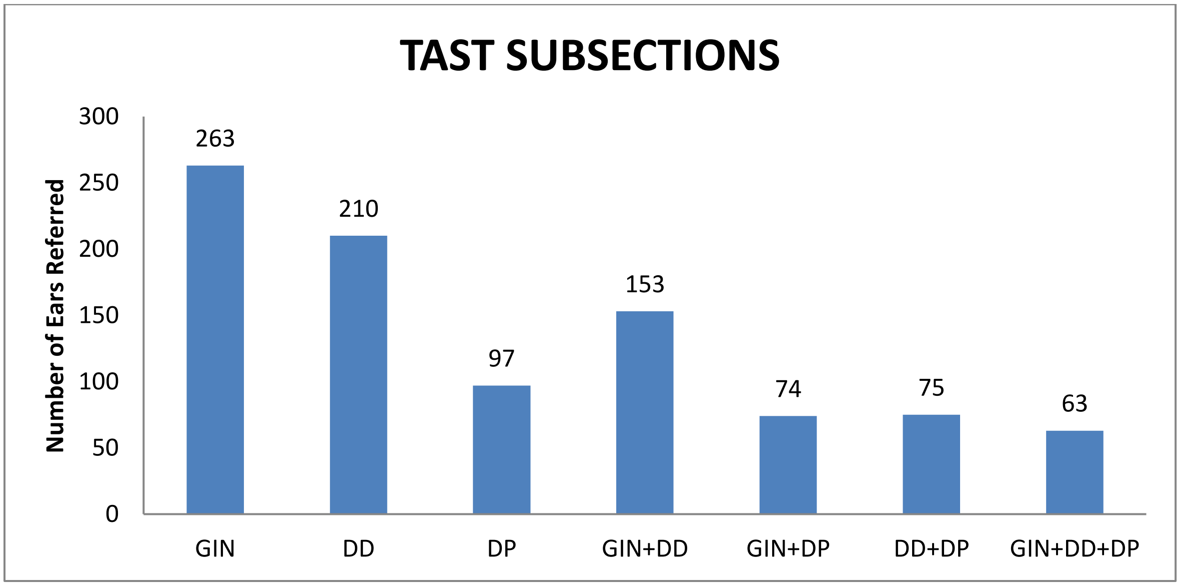


Figure R5: Number of ears referred in one subsection and combination of subsections in TAST (ears that are referred on more than one subsection are represented multiple times).

Table R7 provides information regarding of the number of participants who did not pass the test/s in one or both ears. From the table it can be observed that the maximum number of individuals were referred on the GIN subsection. Out of the 260 participants, 143 (55%) did not pass the GIN subsection, 124 (23.84%) did not pass DD and 85 (16.36%) did not pass the DP subsection.

Table R7: Number of ears that passed or were referred on the TAST subsections in those with normal hearing and those with hearing impairment across the three age groups, with percentage in parenthesis

TAST Subsections		**Normal hearing (Group –I)**				**Hearing Impaired (Groups II)**			
		I-OAa (N=60)	I-OAb (N=60)	I-YA (N=60)	Total (N=180)	II-OAa (N=40)	II-OAb (N=40)	Total (N=8 0)	Overall total (N=260)
GIN	Right ear refer; Left ear pass	0 (0.6)	8 (13.33)	2 (3.33)	10 (5.56)	2 (5)	0 (0)	2 (2..5)	12 (4.62)
	Left ear refer; Right ear pass	0 (0)	9 (15)	1 (1.67)	10 (5.56)	1 (2.5)	0 (0)	1 (1.25)	11 (4.23)
	Both ears refer	23 (38.33)	28 (46.67)	0 (0)	51 (28.33)	30 (75)	39 (97.5)	69 (86.25)	120 (46.15)
	Both ears pass	37 (61.67)	15 (25)	57 (95)	109 (60.56)	7 (17.5)	1 (2.5)	8 (20)	117 (45)
	Total	60	60	60	180	40	40	80	260
DD	Right ear refer; Left ear pass	3 (5)	2 (3.33)	2 (3.33)	7 (3.89)	4 (10)	1 (2.5)	5 (12.5)	12 (4.62)
	Left ear refer; Right ear pass	10 (16.67)	3 (5)	3 (5)	16 (8.89)	3 (7.5)	3 (7.5)	6 (7.5)	22 (8.46)
	Both ears refer	18 (30)	34 (56.67)	5 (8.33)	57 (31.67)	12 (30)	10 (25)	22 (55)	79 (30.38)
	Both ears pass	29 (48.33)	21 (35)	50 (83.33)	100 (55.56)	21 (52.5)	26 (65)	47 (58.75)	147 (56.54)
	Total	60	60	60	180	40	40	80	260
DP	Right ear refer; Left ear pass	0 (0)	4 (6.67)	0 (0)	4 (2.22)	0 (0)	2 (5)	2 (2.5)	6 (2.31)
	Left ear refer; Right ear pass	0 (0)	5 (8.33)	5 (8.33)	10 (5.56)	1 (2.5)	3 (7.5)	3 (3.75)	13 (5)
	Both ears refer	1 (1.67)	9 (15)	3 (5)	13 (7.22)	10 (25)	17 (42.5)	28 (35)	41 (15.77)
	Both ears pass	59 (98.33)	42 (70)	52 (86.67)	153 (85)	29 (72.5)	18 (45)	47 (58.75)	200 (76.92)
	Total	60	60	60	180	40	40	80	260

2.2 Pass / Fail findings of the Diagnostic tests

Figure R6 indicates the number of ears that failed 1 diagnostic test or combination of diagnostic tests, with each ear being represented only once. Figure R7 also represents the number of ears that failed 1 diagnostic test and the combination of diagnostic, but the values represent the number of times each ear failed each of the diagnostic tests.

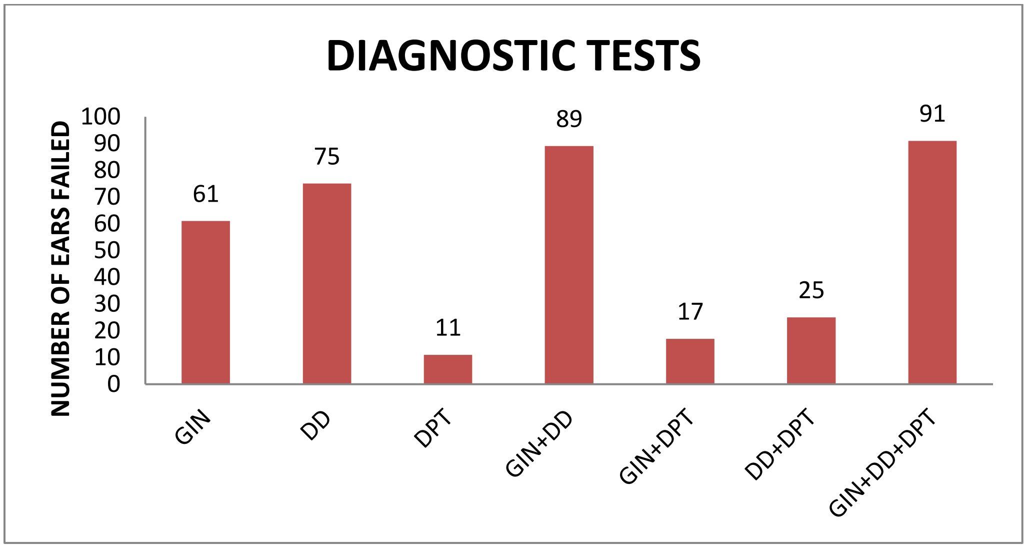


Figure R6: Number of ears failed one diagnostic test or combination of diagnostic tests (ears that fail more than one test are represented only once in the combination of tests that they failed).

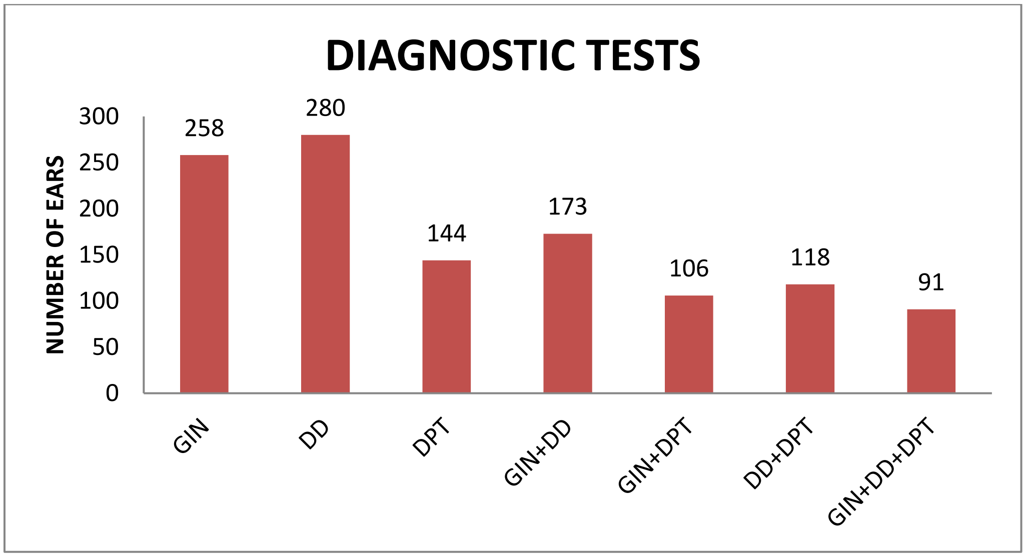


Figure R7: Number of ears failed one diagnostic test and combination of diagnostic tests (ears that fail more than one test are represented multiple times, once under each test).

The maximum number of ears failed DD, followed by GIN. The least number of failures was observed for DPT. The combination of tests that individuals tended to fail most was GIN and DD tests. Further, among the combination of diagnostic tests, the GIN and DD test combination resulted in the larger number of failures.

2.3 Relationship between TAST scores and the diagnostic test scores

The relationship between TAST and the diagnostic tests was determined using Pearson's product moment correlation. The correlation was established for the scores got by the participants on the subsections of TAST and the scores obtained on the corresponding diagnostic test.

Table R8: Pearson's product moment correlation coefficients (r) of the TAST subsection scores and the diagnostic test scores

Diagnostic test →	**GIN**	**DD**	**DPT**
TAST ↓			
GIN subsection	**-0.827****	-0.384**	0.397**
DD subsection	-0.456**	**-0.716****	0.478**
DP subsection	-0.448**	-0.395**	**0.702****
Total TAST scores	-0.826**	-0.563**	0.567**

Note. ** = $p < 0.01$; GIN = Gap-in-noise; DD = Duration discrimination;
DPT = Duration pattern test; DD = Duration pattern

The Pearson two-tailed correlation (Table R8) indicated the presence of a high negative correlation between the scores of the GIN subsection of TAST and diagnostic GIN thresholds ($r = -0.83$) as well as TAST DD subsection scores and the diagnostic DD thresholds ($r = -0.72$). This indicates that as the scores in the TAST subsections increased, there was an improvement in the GIN and DD thresholds. Further, a high positive correlation was obtained between the DP subsection of TAST and its diagnostic counterpart ($r = 0.70$). Thus, the ears with good scores in DP subsection of TAST also had good duration pattern scores in the diagnostic test and vice versa. As seen with the individual subsections of TAST, the total scores of the screening test also had a strong negative correlation with GIN thresholds obtained on the diagnostic test. However, a moderate correlation was obtained between the TAST total score and the diagnostic DD thresholds as well the diagnostic DPT scores, with it being negative for the former and positive for the latter.

2.4 Sensitivity and Specificity of the subsections of TAST

To determine the sensitivity and specificity of the subsections of TAST, the pass / refer information of both the screening test and diagnostic tests was found for each ear. A 2 × 2 decision matrix was formed from the results of a Chi square test for each of the subsections of TAST and the corresponding diagnostic test (Table R9a, R9b, & R9c). The analysis was done using the data of all the participants (Group I-OAa, Groups I-OAb, Group I-YA, Group II-OAa, & Group II-OAb).

Table R9: True positives, false positives, false negatives and true negatives of the TAST subsections for all 520 ears for a) GIN; b) DD; and c) DP subsections of TAST

Table R9a

TAST GIN Subsection	**Diagnostic GIN Test**		**Total**
	Fail	**Pass**	
Refer	242	21	263
Pass	16	241	257
Total	258	262	520

Table R9b

TAST DD Subsection	**Diagnostic DD Test**		**Total**
	Fail	**Pass**	
Refer	197	13	210
Pass	83	227	310
Total	280	240	520

Table R9c

TAST DP Subsection	**Diagnostic DP Test**		**Total**
	Fail	**Pass**	
Refer	87	10	97
Pass	57	366	423
Total	144	376	520

The sensitivity and specificity of TAST were calculated using the equation 1 and 2, respectively. The sensitivity was calculated separately for each subsection of TAST in relation to the corresponding diagnostic temporal processing diagnostic test (Table R10).

$$\text{Sensitivity} = \frac{\text{True Poisitve}}{\text{True Positive} + \text{False Negative}} \text{ X } 100 \qquad \ldots\ldots\ldots\ldots \; \mathit{Equation}\ 1$$

$$\text{Specificity} = \frac{\text{True Negative}}{\text{True Negative} + \text{False Positive}} \text{ X } 100 \qquad \ldots\ldots\ldots\ldots \; \mathit{Equation}\ 2$$

Table R10: Sensitivity and specificity of TAST subsections for all 520 ears

Subsection ↓	**Sensitivity**	**Specificity**
GIN	93.7%	91.98%
DD	70.35%	94.58%
DP	60.41%	97.34%

2.5 Cut-off criterion for referral for TAST

In order to determine the number of subsections of TAST that needed to be considered when deciding to pass or refer an individual, further analysis was done. The sensitivity and specificity of TAST was calculated for three criteria (referred on 1 subsection of TAST, referred on 2 subsections of TAST, & referred on 3 subsections of TAST) using equations 1 and 2. An individual was diagnosed to have a temporal processing problem if he / she failed any of the temporal processing diagnostic tests even in one ear.

Table R11: Sensitivity and specificity of TAST and different cut-off of affected subsections

No. of subsections with low scores on TAST	Pass	Refer	Sensitivity	Specificity
≥ 1	160	360	85.9%	88.74%
≥ 2	112	408	68.48%	100%
3	62	458	54.38%	100%

As can be observed in Table R11, the sensitivity was highest (85.9%) when the participants were unsuccessful one of the subsections, but the specificity was the least (88.74%). As the number of affected subsections increased, the sensitivity dropped but the specificity increased (Table R11 & Figure R8). Although the specificity was higher (100%) when the individuals were referred on two subsections, the sensitivity was considerably poorer (68.48%). Hence, it is recommended that even if an individual obtains poor scores on only one subsection, in one ear, they should be referred for diagnostic testing.

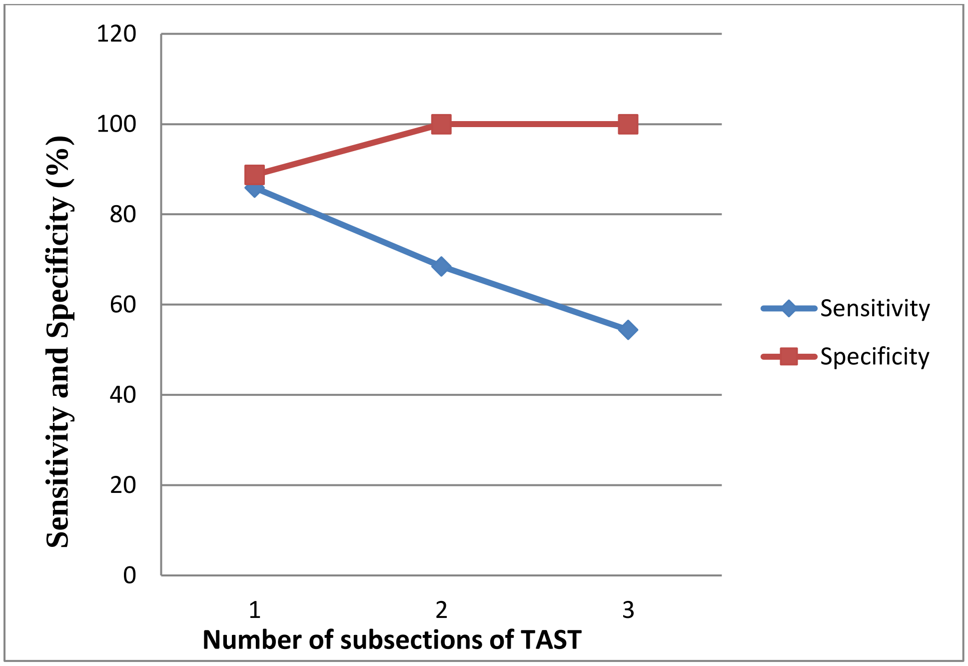


Figure R8. Sensitivity and specificity of TAST as a function of number of subsection of the TAST that a person was referred.

Kappa measure of agreement was also calculated between the number of ears that were referred on TAST using different cut-off criteria (i.e. referred on 1, 2 or 3 subsections) and the diagnosis of a temporal processing problem (failure on any of the diagnostic tests). As can be seen in Table R12, the agreement was highest when a cut-off criterion of one subsection was considered. Thus, the agreement between the screening test and the diagnosis of temporal processing disorder was the highest when individuals were considered at-risk for the condition when they obtained low scores on just one subsection of TAST.

Table R12: Agreement between TAST and diagnostic tests with different cut off for subsections.

No. of subsections with low scores on TAST	Kappa measure of agreement (K)	Significance level
≥ 1	0.69	p < .001
≥ 2	0.20	p < .001
3	0.10	p < .001

2.6 Test Re-test Reliability of TAST

To check the reliability of TAST, 10% of the normal hearing population (N = 18) were tested once again 3 months after the initial evaluation. Equal number of participants were tested from the 3 age groups (I-OAa, I-OAb, & I-YA), with half of them in each age group being native speakers of Kannada and half native speakers of Marathi. The results of Pearson's product moment correlation for the 36 ears for each subsection of TAST are represented in the Figures R9a, R9b, and R9c.

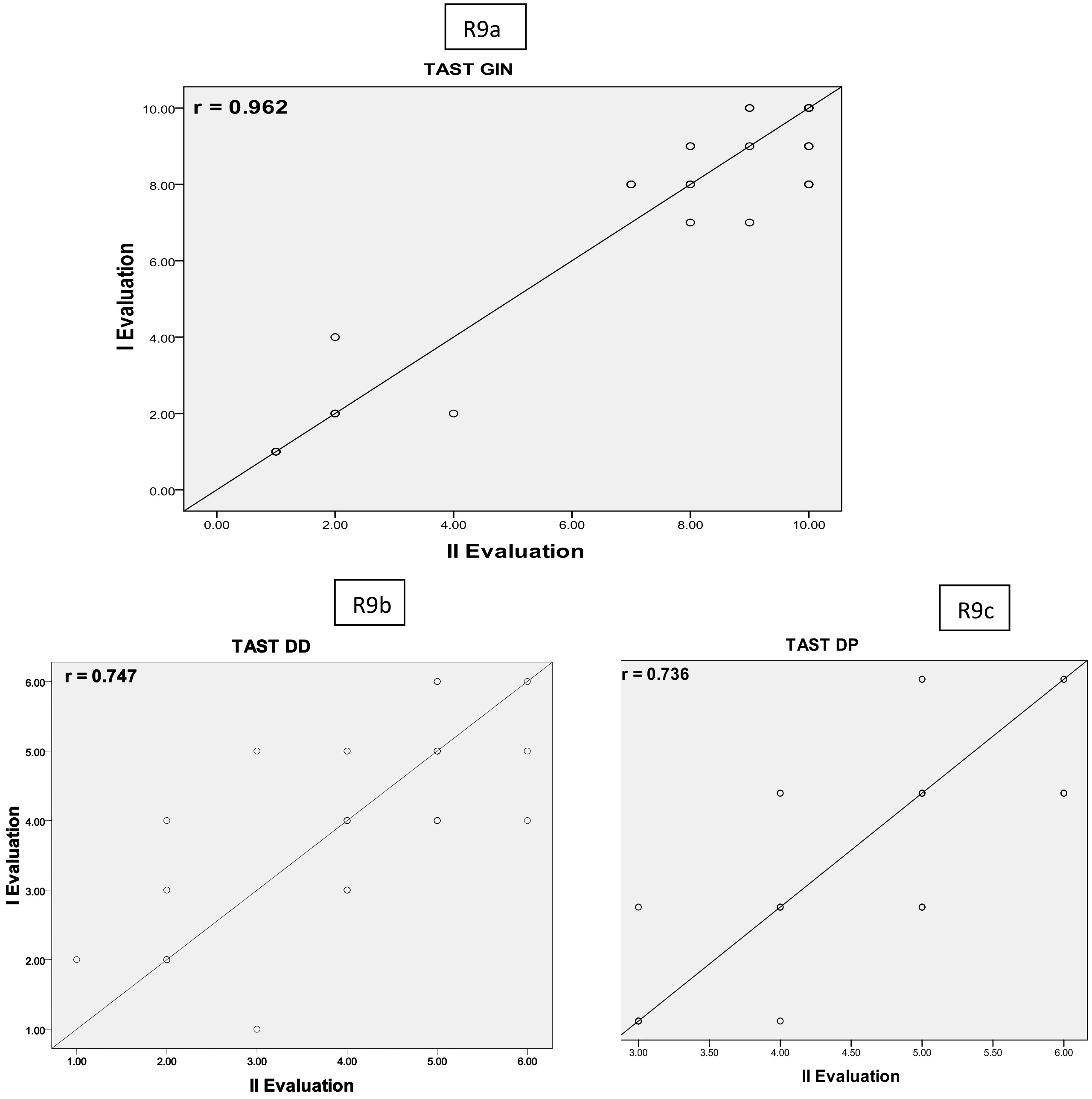


Figure R9: Scatter plot of TAST test-retest reliability for the (a) Gap-in-noise subsection (GIN), (b) Duration discrimination subsection (DD) and, (c) Duration pattern subsection (DP)

The correlation between the two evaluations was significantly high ($p < 0.01$). The scores of the GIN subsection had the highest correlation ($r = 0.96$), followed by DD ($r = 0.74$) and DP ($r = 0.73$).

Thus, from the findings of the study it can be observed that there was no significant difference between the native speakers of Kannada and Marathi for two of the diagnostic temporal processing tests (GIN & DPT) in the young adults. On the other hand a significant difference was found between the language groups for DD. Further, in none of the tests was there a difference in performance between males and females as well as the two ears of the young adults. From the newly developed screening test, TAST, it was noted that the subsection in which the maximum number of individuals were referred was GIN, followed by DD. Relatively few individuals were referred on the DP subsection. Further, among those who were referred on more than one subsection, the combination of GIN + DD as well as GIN + DD + DPT were high, with the former being higher. On the diagnostic temporal processing tests, it was seen that the number of individuals who failed only one test was lesser when compared to those who failed combination of tests. Among those who failed on only one test, the majority failed either GIN or DD and very few failed DPT. A similar number of individuals failed the combination of GIN + DD and GIN + DD +DPT. The correlation between the subsections of TAST was high with the corresponding diagnostic test. However, the overall score of TAST had the highest correlation with the diagnostic test GIN, with it being lesser for DD and DPT. Among the subsections of TAST, GIN had the highest sensitivity (93.7%), followed by DD (70.35%) and DPT had the least sensitivity (60.41%). The specificity for all the subsections was high, with it being above 90% for all subsections. Based on the findings of the sensitivity and specificity with different cut-off scores, it is recommended that an individual should be considered to be at-risk for temporal processing problems if they are referred on any one subsection of TAST. A test-retest reliability indicated that TAST had a moderately-high to high reliability.

4. Discussion

The present study was designed to develop a tool to screen temporal processing abilities in adults. The study also evaluated whether temporal processing performance varied depending on the native language of individuals (Marathi and Kannada), age and gender. Different components of temporal processing, temporal resolution, temporal patterning and temporal discrimination were assessed using GIN, DPT and DD tests respectively. The measures included for analysis were GIN threshold, total no. of gaps identified, ratio between total no. of gaps identified and total no. of gaps presented, DPT scores and DD scores.

Comparison of temporal abilities of native speakers of Marathi with Kannada

The GIN threshold, total no. of gaps identified, ratio between total no. of gaps identified and total no. of gaps presented, DPT scores were found to similar in the native speakers Marathi and native speakers of Kannada. However, the duration discrimination threshold was poorer in the native speakers of Marathi in comparison to the native speakers of Kannada.

To the best of the researchers' knowledge, there are no studies in literature have investigated the influence of native language on the temporal abilities using non speech tests. However, some inferences can be drawn based on the existing review of literature. The normative data obtained by different investigators for GIN and DPT are similar even though the native language of the participants of different investigations were not same (Helfer & Vargo, 2009; Neijenhuis, Snik, & van den Broek, 2003; Weihing, Musiek, & Shinn, 2007). While discussing the procedural, stimulus and subject related factors across studies most of the authors agree to the fact that GIN scores are similar irrespective of different language background (He et al., 1999; Musiek et al., 2005c),

The results of the present study indicate a language based differences in some aspects of temporal abilities of normal hearing individuals. It is plausible that inherent differences in temporal characteristics of these two languages lead to differences in some aspects of temporal skills of the individuals. Differences in temporal characteristics of different languages has been reported in literature. There are differences in temporal characteristics of Kannada, an Indo-Dravidian language and Marathi, an Indo-Aryan language. One of the differences is in terms of the use of aspirated speech sounds. Although aspirated speech sounds are present in both the languages, aspirate sounds are more common among Indo-Aryan languages such as Marathi (Bhaskararao, 2011); (Ramakrishna et al., 1962). The frequency of occurrence of both voiced and unvoiced speech sounds in Marathi were also reported considerably higher compared to Kannada (Ramakrishna et al., 1962). Temporal characteristics of speech sounds are used in differentiating between aspirated and unaspirated sounds. For example, (Patil & Rao, 2013) have observed that in Marathi one of the distinguishing properties of aspiration in voiced plosives is duration. Rami et al. (1999) noted that the voice onset time between aspirated and unaspirated unvoiced stops was statically significantly different in Gujarati. They report of a resemblance between Gujarati, Marathi and Hindi.

Further studies are required to confirm whether a difference really exists between the temporal abilities of persons with different native language. However, the outcome of this study suggests that one should be cautious while using the same norms across languages to assess different aspects of temporal abilities. The results of this study indicate that while administering GIN and DPT, common normative data can be used for speakers of Indo-Dravidian and Indo-Aryan languages.

Effect of age

The effect of age on temporal processing was investigated in this study and results showed a clear trend of decrease in temporal abilities with increase in age. The effect was similar for both right and left ears. There was no significant effect of gender. The effect of age observed in this study is in consonance with the report of a previous investigation conducted by, John et al. (2012) who evaluated the effect of age on GIN test. The older adults (mean age of 57.3 years) with essentially normal hearing had higher GIN threshold when compared to young adults. Similar to this study, they have also not reported of any effect of ear across the groups. Another study in this line utilized detection of temporal gaps in sinusoidal signals as a function of frequency in elderly subjects with ‘‘near-normal’’ hearing audiometric thresholds <25 dB HL from 250 to 2000 Hz to estimate age effect on temporal processing (Moore, Peters, & Glasberg, 1992). Results revealed that elderly subjects with near-normal hearing had higher gap detection thresholds than their young counterparts. A few studies reported in literature showed poorer gap detection thresholds in elderly with near normal hearing sensitivity even though these studies had procedural variation when compared to the present study (Kumar & Sangamanatha, 2011; Snell, 1997). Though results of most of the studies indicate that temporal processing deteriorate with age, contradictory results are also reported in literature occasionally.

Prem et al. (2012) studied temporal resolution using GIN test in two age groups; Group 1: 17-40 years of age and Group 2: 41-55 years of age. The gap detection threshold and total percentage scores were measured. The results showed no significant effect of age on both the variables measured. This difference in the findings of this study from the present study as well as other above mentioned studies could be due to the difference in age group studied. Earlier studies have not compared the different parameters of GIN test, the total no. of gaps identified and ratio between total number of gaps identified and total number of gaps. The findings of the present study with no significant effect of ear and gender are in agreement to previously reported studies (John et al., 2012; Prem et al., 2012).

The effect of age on temporal ordering observed in the present study is in agreement with some of the previous investigations which revealed that the results of DPT in elderly individuals with normal hearing is significantly lower than the normal range and there is no significant ear effect (Kolodziejczyk & Szelag, 2008; Parra et al., 2004). Kumar and Sangamanatha (2011) also reported similar results where DPT scores started to decline in sixth decade of life. The decrease in DPT performance in older individuals could be attributed to a weaker processing of stimuli in the central auditory nervous system. Lesions in the posterior part of the temporal lobe, insular cortex and brainstem have been shown to reduce temporal processing ability (Bamiou et al., 2006)). It is possible that a general deterioration in the regions responsible for temporal processing occurs with age, as indicated by the impairment in both of the temporal tasks evaluated in the present study (GDT & DPT) in the older individuals.

Similar to the results of present study, Kumar and Sangamanatha (2011) also reported poorer duration discrimination threshold with increasing age in spite of variation in procedure used. Contradictory results are reported by (Phillips et al., 1994) who studied auditory duration discrimination ability with and without backward interference in young as well as elderly listeners with normal hearing. They found no significant effect of age on duration discrimination task carried out without interference. These differences among studies in findings could be attributed to procedural variations and very small sample size used in study.

Thus, to conclude the results of numerous reports on temporal processing and aging based on GIN, DPT and DD tests including the present study, funnels down to the fact that temporal resolution ability decrease with increase in age in a progressive manner. This change is similar across ears. These results support the notion that older adults have more difficulty processing time-varying cues, and perceptual difficulties observed might be related to factors affecting neural synchrony (Strouse et al., 1998).

Effect of hearing loss

The gross outline of the outcomes of all the tests can be drawn as decreased performance on temporal processing ability in presence of a hearing loss. That is the scores of participants with hearing loss was poorer when compared to the age matched normal hearing groups. The possible physiological explanation for the obtained findings can be drawn from animal research which has shown that peripheral hearing loss alters spatial and temporal response properties throughout the central auditory system (Willott, 1996). This can lead to poor performance on temporal task by elderly individuals with hearing loss.

In the present study the older adults with hearing loss showed higher GIN threshold when compared to participants with no hearing loss. The elevation in GIN threshold can be attributed primarily to loss of audibility. This is not surprising given the association between gap detection thresholds and hearing level seen in previous studies (Leigh-Paffenroth & Elangovan, 2011; Nelson & Thomas, 1997). John et al. (2012) study provides similar evidence of significant deleterious effects of hearing loss on GIN test performance. Roberts and Lister (2004) found that both within and across channel gap detection processing was affected in individuals with hearing loss. However, in contrast, Moore et al. (1992) reported of no significant effect of age on temporal processing based on their investigation using GIN. This difference in the findings of these studies could be attributed to difference in procedure involved.

The other variables investigated in the present study such as total no. of gaps identified and ratio between total no. of gaps identified and total no. of presented also showed a declines in individuals with hearing loss in comparison to individuals with normal hearing. However, these variables have not been explored by earlier researchers. Thus, this study adds evidence to the fact that temporal resolution ability deteriorates with hearing loss.

The DPT scores were found to be lower in individuals with hearing loss than their normal counterparts. Highly equivocal findings are reported in the literature on effect of hearing loss on DPT scores. A study conducted by Neijenhuis, Tschur, and Snik (2004) lines up with the findings of the present study that DPT is affected by even mild hearing loss. However, another investigation by Musiek, Baran, and Pinheiro (1990b) found no significant effect of cochlear hearing loss on DPT scores. This was further supported by de Oliveira Matos and Frota (2013) through their study by concluding that the temporal ordering evaluated by the DPT is not influenced by mild to moderate sensorineural hearing loss. The possible difference in these studies arise from differences in the investigations such as the age group selected for investigation, difference in diagnostic criteria, difference in pathology behind each group. Hence, in order to have a consensus on the effect of hearing loss on DPT, further investigations are invited which should control the above factors at its finest level to have a comprehensive outcome.

The results of the present study also showed a significant effect of hearing loss for DD threshold obtained from both native speakers of Kannada as well as Marathi in the age range of 60- 70 years. However, the elderly subjects with hearing loss did not differ much from control group in terms of DD threshold obtained from both the native speakers in the age range of 50-59.11 years. In opposition to present study findings, Grose, Hall, and Buss (2004) reported that there was no significant effect of cochlear hearing loss on duration discrimination task. Their findings were further supported by other investigators by conducting DD test in elderly and concluding that hearing loss had no systematic effect on discrimination performance in elderly subjects with hearing loss aged 65-76 years (Fitzgibbons & Gordon-Salant, 1995; Gordon-Salant & Fitzgibbons, 1999). The difference in findings of these investigations may be attributed to difference in pathology behind each group, difference in age group selected etc. Hence by walking away from the reports of most of the studies the present study heads to the possible effect of hearing loss on DD beyond an age range, which needs to be investigated in further detail.

In the present study when the temporal abilities of native speakers of Marathi were compared with Kannada, a difference was found only for DD threshold. With advancing age there was a decline in scores on all the parameters assessed. The performance on various temporal tasks in subjects with hearing loss was poorer in comparison to those with normal hearing. The results of the present study indicate that hearing loss do have a deleterious effect on one's temporal processing skills especially beyond a particular age range. It is plausible that younger adults with hearing loss develop compensatory mechanism but older adults are unable use the compensatory strategies.

Pass / Refer findings of TAST

The results of the study indicate that out of the 520 ears that were screened using TAST 64% had poor performance on one or more of the subsections of TAST highlighting that a high percentage of adults are at-risk for temporal processing problems. Among those who were found to be at-risk for temporal processing problems, 47.9% were referred on only one subsection of TAST. The remaining 52.1% (174 ears) were referred on two or more subsections of TAST. Of these 174 ears, in 93.68% they fared poorly on the GIN subsection. These findings of the study indicate that a large percentage of individuals have temporal processing problems that needs further attention.

On comparison of the younger group with the two older groups it can be noted that the latter two groups were more prone to being at-risk for temporal processing problems when compared to the former group adults. The majority of these individuals had difficulties in both ears, although a few of them did have problems in only one ear. Overall, from the results of the subsections of TAST, it can be construed that older adults had most difficulty with the GIN subsection, followed by DD and DP subsections. The number of individuals with difficulty in the DP subsection was considerably less compared to the other two subsections (Table R7).

In those with *mild to moderate hearing loss,* the risk for temporal processing problems was found to almost double when compared to those in the same age group without hearing impairment. This doubling occurred only for the GIN subsection and DP subsection of TAST. With regards to the DD subsection of TAST, either similar percentage (for OAa) or a reduction in the percentage of individuals (for OAb) was seen in those with hearing loss. The findings of DD in could have occurred due to individual variability being larger for this subsection. This reduction cannot be interpreted to indicate that DD performance decreases with the presences of a hearing loss. Rather it is on account of the exceptionally large number of individuals with normal peripheral hearing in the oldest group having difficulty in DD. This led to a relative lesser number having difficulty on the subsection in the age matched group with hearing impairment.

It has been noted that those with hearing impairment had poorer temporal resolution abilities when compared to those with no hearing impairment (Glasberg et al., 1987; Madden & Feth, 1992; Moore & Glasberg, 1988; Phillips et al., 2000). In contrast, it has been noted by Gordon-Salant and Fitzgibbons (1999) that temporal resolution is not affected in those with hearing impairment. Thus, a larger number of studies indicate that individuals with hearing impairment have more difficulty with temporal resolution when compared to those with normal hearing. Unlike the findings on temporal resolution, it has been noted that for duration discrimination those with hearing impairment preformed similar to those with normal hearing (Abel et al., 1990; Bergeson et al., 2001; Fitzgibbons & Gordon-Salant, 1994; Gordon-Salant & Fitzgibbons, 1999; Gordon, Papsin, & Harrison, 2006). Thus, it can be seen that the performance of those with hearing impairment varied depending on the temporal aspect that is administered.

From the findings of the current study and that given in literature, it can be interpreted that temporal processing problems can be picked-up more readily using the GIN and DD subsections compared to the DP subsection in those with normal peripheral hearing. However, in those with mild to moderate hearing loss, temporal processing problems continued to be picked-up more frequently using GIN, but occurred in a similar manner with the other two subsections of TAST.

The order of diagnostic test that the individuals failed varied slightly from the order that difficulty was found on the subsections of TAST. A larger number of ears were found to fail on the diagnostic DD test followed by the diagnostic GIN test. However, this difference was not very large. On the other hand, the number of ears that failed DPT was considerably less. Thus, it can be inferred from the findings of TAST as well as the diagnostic tests that temporal difficulties occurred more with GIN and DD, but not so much with DP.

A possible reason why GIN and DD are more difficult than DP is because the duration the stimuli. It has been reported by Plomp and Bouman (1959) and Richards (1977) that perception of short duration stimuli are considerably more difficult than perception of stimuli that are longer in duration. GIN entails perception of much smaller temporal cues compared to the stimuli of the other two subsections. Additionally, the duration difference in the stimuli used for the duration pattern subsection (500 ms & 1000 ms) were longer than that used for duration discrimination (500 ms & 650 ms). This could have led to GIN being most difficult, followed by duration discrimination and duration pattern. Further, it can also be stated that temporal ordering is not a temporal aspect that is frequently affected in individuals.

Due to the large number of individuals with hearing loss who were found to be at-risk for temporal processing problems on some of the subsections of TAST, it is recommended that as a routine, older individuals with hearing be screened for the presence of the condition. This should be done provided the degree of hearing loss permits evaluating them.

Pass / Fail findings of the diagnostic tests

The findings of the diagnostic tests indicated that more ears failed the duration discrimination test (280 ears) compared to GIN (258 ears). However, the number of ears that failed each of these diagnostic tests was not very different. On the other had considerably lesser number of ears failed the duration pattern test (144). Additionally, the number of ears that failed a combination of GIN and DD was more (173 ears) when compared to other combinations of tests where DPT occurred as can be seen in Figure R7.

These findings substantiate that perception of short duration stimuli such as gaps embedded within a signal as well as duration discrimination is considerably more difficult when compared to DPT. The pattern test made use of longer stimuli, thereby possibly making the task easier for the participants. These findings are similar to what was noticed between the subsections of the screening tests, TAST. As mentioned earlier, the longer duration of DPT probably made the task easier compared to the shorter stimuli required to be discriminated in the diagnostic GIN and DD tests.

Relationship between TAST and the diagnostic tests

Among the diagnostic tests for temporal processing, the maximum number of failures was observed for the DD test whereas in the screening test the maximum failure was seen in the GIN subsection. However, similar to what was observed in the screening test, among the combination of diagnostic tests, the GIN and DD test combination resulted in the larger number of failures. From Figures R5 and R7 it can be observed that similar number of ears were referred / failed the GIN subsection/test. The number of ears having difficulty with DD was considerably more when tested using the diagnostic test compared to the screening test. This occurred despite the cut-off criteria for the screening DD subsection and the diagnostic DD test being the same (i.e. 200 ms). It is possible that the participants paid more attention during the screening test, as the test was short. On the other hand they may have not paid the same amount of attention during the diagnostic test due to longer duration taken to administer the test.

All three subsections of TAST had high significant correlations with their corresponding diagnostic tests (Table R8). This correlation was the highest between the GIN subsection of TAST and the diagnostic GIN test. Further, the overall TAST scores also had the highest correlation with the diagnostic GIN test. It can be construed from these findings that with or without the scores of the DD and DPT subsections of TAST the correlation of the screening test with the diagnostic GIN test did not alter. Despite this it is recommended that all three subsections of TAST be included as the individuals indentified by each of the subsections were not the same. This can be observed in Figure R6 that indicates that different individuals failed on different diagnostic temporal processes. Thus, it can be stated that temporal processing difficulty varies across individuals.

Sensitivity and specificity of subsections of TAST and cut-off criteria for referral

The true positive and false negatives were calculated separately for each of the subsections (Table 10). This was done as there are no standard criteria to decide whether an individual should be diagnosed to have temporal processing problem or not based on the combination of tests for the condition. While the specificity for all three subsections of TAST was high (ranging from 91.98% to 97.34%), the sensitivity varied depending on the subsection of

TAST. The sensitivity was highest for the GIN subsection (93.7%) followed by the DD subsection (70.35%). The DP subsection was found to be least sensitive (60.41%). Although the sensitivity and specificity for TAST was highest for the GIN subsection of the test, it is maintained that the decision to refer or pass an individual based on their temporal processing abilities should be based on their performance of all three subsections. This is considered essential since the overall sensitivity of the screening test was the highest when one or more subsections were considered, as can be seen in Table 11. Although the specificity increased to 100% when two or more subsections were considered, it resulted in a large drop in the sensitivity. As it is more essential that true positives be identified, although at the cost of over referral of a few individuals, it is recommended that a cut-off of one subsection be considered when referring individuals for diagnostic evaluation of the condition. Thus, it is considered essential to refer individuals for detailed diagnostic evaluation even if they obtain low scores on just one subsection of TAST.

From the findings of the study it can be interpreted that the screening test can be used effectively in adults with and without hearing impairment, provided the loss is not greater than a moderate level. This can be recommended as the population considered while establishing the sensitivity and specificity included a diverse age group and those with and without hearing impairment. The test has added advantage that the actual test stimuli are non-linguistic. Thus, the test can be used with individuals from different language backgrounds with just the instructions being replaced in the native language of the speaker. From the analyses carried out on the Dravidian language (Kannada) and Indio-Aryan language (Marathi) using the diagnostic tests, it can be seen that temporal processing is similar in the two languages. This is true for the majority of the temporal aspects that were studied. Thus, temporal variations seen in Dravidian and Indio-Aryan languages do not impede the use of the newly developed screening test, TAST.

Test-retest reliability of TAST

The test-retest reliability carried out on 10% of the normal hearing participants revealed that the test was highly reliable (Figure 9). This was especially true for the GIN subsection of the screening test that had the highest correlation between the first and the second evaluations.

Hence, it can be inferred that the TAST is not only sensitive to the temporal processing difficulties, is also a reliable test.

5. Conclusions

From the findings of the study it can be interpreted that most temporal abilities of native speakers of Marathi are comparable with Kannada speakers. A difference was found only for DD threshold. Thus, temporal variations seen in Dravidian and Indio-Aryan languages do not result in a great difference in temporal perception. With advancing age it was noted that there was a decline in scores on all the parameters assessed. The performance on various temporal tasks in participants with hearing loss was poorer compared to those having normal hearing. The results of the study indicates that hearing loss does result in a deterioration in temporal processing skills, especially in older adults. It is plausible that younger adults with hearing loss develop compensatory mechanism but older adults are unable use the compensatory strategies.

Further, the results indicate that the newly developed screening test, TAST, can be used effectively in adults with normal hearing and those with mild to moderate hearing impairment. As the screening test had a high sensitivity and specificity in a diverse age group and those with and without hearing impairment, it can be recommended to screen for the presence of temporal processing problems. The test has added advantage that the actual test stimuli are non-linguistic. Thus, the test can be used with individuals from different language backgrounds with just the instructions being replaced in the native language of the speaker. Thus, the temporal variations seen in Kannada and Marathi do not impede the use of the newly developed screening test, TAST.

Acknowledgement

We wish to thank the All India Institute of Speech and Hearing, Mysuru for funding this project and Bharati Vidyapeeth Deemed University for providing permission to carry out the project at Pune.

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7. Appendix

Manual for the Temporal Ability Screening Test (TAST)

Developed by #Asha Yathiraj, ^Vanaja CS, #Indukala KV, and #Mittali Joshi

Developed in 2013

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The temporal ability screening test (TAST) was developed with the aim to identify auditory temporal processing problems in adults. The test comprises of three subsections that include 'Duration pattern (DP)', 'Gap in noise (GIN)' and 'Duration discrimination (DD)'. The CD version of the test has been prepared in such a way that it is possible to evaluate both ears without having to make any changes in the settings once the test commenced. The test contains a calibration tone, general instructions, and specific instructions for each subsection. Additionally, it contains demonstration items, practice items and test items.

The test commenced with the general instruction regarding the entire test, spoken by a female speaker. Prior to the stimuli used for screening, a 1 kHz calibration tone is provided to manipulate the settings to obtain the required output level. Following this, specific instructions for each subsection are provided by the same female speaker. Instructions for each subsection are given just prior to the practice items, which are followed by the test items for the subsection. The practice items commence with a recording of a participant demonstrating how to respond to a stimulus, followed by an instruction encouraging the participant being tested to respond. The demonstrations are provided only for DD and DP. No demonstration is given for GIN as it requires a pointing response that cannot be recorded. The test items are presented subsequent to the practice items. A brief instruction alerts the listener before the stimuli are presented to the opposite ear (i.e. "Now listen in your other ear). Initially, the GIN subsection is tested followed by DD and DP. The screening test is designed such that for each subsection both ears are evaluated before the next subsection is presented.

The description of each of the subsections of TAST is provided in Table A1. The table provides information for each of the subsections in terms of the auditory process that is evaluated, description of the stimuli, demonstration items, practice items, number of test stimuli, inter stimulus interval, instructions, mode of presentation, responses to be elicited, scoring procedure and total score for each subsection.

Table A1. *Details of subsection of TAST*

	TAST Subsections		
	Gap In Noise (GIN)	**Duration Discrimination (DD)**	**Duration Pattern (DP)**
Processes tested	Temporal resolution	Temporal discrimination	Temporal ordering
Stimuli	Six spurts of broadband noise of 6 s duration with or without gaps of 7 ms inserted.	Pairs of 1000 Hz tones having durations of 500 ms and 650 ms.	Triads of 1000 Hz tones having short duration of 500 ms (S) and long duration 1000 ms (L), used to form different duration patterns.
Demonstration item	--	1 pair per ear; *1st pair*: Tones having different durations (500 ms & 700 ms). *2nd pair*: Tones having same duration (500 ms & 500 ms).	1 pattern per ear; *1st pattern*: LSL *2nd pattern*: SLS
Practise item	1 broad band noise containing 3 gaps per ear; *Gaps in 1st stimulus*: 10 ms, 8 ms, & 10 ms *Gaps in 2nd stimulus*: 8 ms, 10 ms, & 8 ms	1 pair per ear; *1st pair:* Tones having different durations (500 ms & 700 ms) *2nd pair*: Tones having different durations (500 ms & 700 ms)	1 pattern per ear; *1st pattern* : SLS *2nd pattern* : LSL
Number of Test items per ear	5 broadband noise spurts with nine 7 ms gaps; 1 broadband noise spurt with no gap	4 pairs of different durations; 2 pairs with same duration	6 different patterns per ear
Inter stimulus interval	5 s	5 s	6 s
Mode of presentation	Monaural	Monaural	Monaural

Presentation level	40 dB SL	40 dB SL	40 dB SL
Response	Press button / lift finger	Verbal response to indicate whether the 2 stimuli presented are same or different.	Verbally respond the duration pattern of the 3 stimuli presented (Eg Long, short, short for a LSS pattern)
Scoring	‘1’ for every correct response & ‘0’ for every incorrect response	‘1’ for every correct response & ‘0’ for every incorrect response	‘1’ for every correct response & ‘0’ for every incorrect response
Total score	10	6	6

Pre-requirements for the administration of different subtests of TAST

- A laptop or desktop computer with a CD-ROM.
- A calibrated two channel diagnostic audiometer through which the recorded material can be routed from the computer having supra-aural headphones.

Test environment

All the tests should be carried out in a well illuminated, air-conditioned, acoustically treated set-up. The ambient noise levels in the room should be within specified limits as per American National Standard Institute specifications (ANSI S3.1 1999).

Instructions to the clinician

Prior to the placement of the headphone on the individual being tested, they should be instructed to listen carefully to the instructions that they would hear through the headphones and carryout the tasks as instructed.

Instructions recoded in the CD for the three subtests of TAST

Gap In Noise

“Please listen carefully. You will hear some noise. Within the noise you may hear gaps. The gap will sound like a change in the noise. Please raise your finger as soon as you hear the gap.” (The alerting title *‘Practise items’* will be heard prior to the practice items. This is followed by the alerting title *‘Test items’,* heard prior to the presentation of the test items, after which the alerting message ‘*Now please respond in your other ear’* before the test items are presented in the opposite ear)**.**

Duration Discrimination

"You will hear two sounds. They may have same or different durations. Listen carefully and say whether they have same or different durations. Please first listen to how you should respond. You will first hear a sample of how the response should be given". (Demonstration of how the task is to done will be heard). "Now you try." (The alerting title *'Practise items'* will be heard prior to the practice items. Subsequent to this the alerting title *'Test items'* will be heard prior to the test items followed by the alerting message '*Now please respond in your other ear'* before the test items are presented in the opposite ear)**.**

Duration Pattern Test

"You will hear 3 sounds one after the other. The sounds will have long or short durations. Listen carefully and say whether the 3 sounds are long or short, in the order in which you hear them. If the 3 sounds are short, long, and long, you will say short, long, long. Please listen to how you should respond." (Demonstration of how the task is to done will be heard). "Now you try." (The alerting title *'Practise items'* will be heard prior to the practice items. This is followed by the alerting title *'Test items',* heard prior to the presentation of the test items, after which the alerting message '*Now please respond in your other ear'* before the test items are presented in the opposite ear)**.**

Recording of responses:

The responses of the participants should be noted in the scoring sheet provided in Table A2. The responses of the individual should be noted for each of the subsections of TAST.

Table A2. Scoring sheet for TAST

Temporal Ability Screening Test (TAST) SCORING SHEET						
Name :		Age / Sex:		Mother Tongue :		
TEST		Right ear		Left ear		Remarks
		Response	Score	Response	Score	
Gap In Noise	1) G – G - N					☐ Pass ☐ Refer
	2) N – G - G					
	3) N – N - N					
	4) N - N - G					
	5) G - N - N					
	6) G – G - G					
	Total :		/6		/6	
Duration Discrimination Test	1) T					☐ Pass ☐ Refer
	2) T					
	3) C					
	4) T					
	5) C					
	6) T					
	Total :		/6		/6	
Duration Pattern Test	1) LLS					☐ Pass ☐ Refer
	2) SLS					
	3) SSL					
	4) SLL					
	5) LSL					
	6) LSS					
	Total :		/6		/6	

Note: ‘G’: Gap; ‘N’: No Gap; ‘L’: Long; ‘S’: Short; ‘T’: Test item; ‘C’: Catch trial

Scoring of responses:

Scoring of the responses should be done using the response key given in Table A3.

Table A3. Response key for the TAST subsections

Subsections	**Stimulus No.**	**Right track**	**Left track**
Gap in Noise	1.	2 Gaps	2 Gaps
	2.	1 Gap	2 Gaps
	3.	No Gap	No Gap
	4.	3 Gaps	1 Gap
	5.	2 Gaps	1 Gap
	6.	1 Gap	3 Gaps
Duration Discrimination	1.	T	T
	2.	C	T
	3.	T	C
	4.	C	T
	5.	T	C
	6.	T	T
Duration Pattern	1.	SLS	LLS
	2.	SSL	LSL
	3.	LSL	LSS
	4.	LLS	SLL
	5.	SLL	SLS
	6.	LSS	SSL

Pass / Refer criteria

Table A4 shows the scores required to pass the TAST. In order to consider an individual as having passed TAST they should get scores equal to or above the values given in the table. The individual should be referred for detailed temporal processing testing if they obtain scores below the pass criteria in any of the subsections in either one or both ears.

Table A4. Pass criteria for the following subtests of TAST

TAST Subsection	Maximum possible scores	Pass criteria
Duration pattern test	6	4
Gap in noise	6	5
Duration discrimination test	6	5

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