Some Aspects of Temporal Processing Deficits in Individual with Learning Disability

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Abstract

Individual with learning disability are likely to have auditory temporal processing deficit. Auditory temporal processing deficits lead to inability to process three main temporal features of speech sounds such as envelope, periodicity and fine structure cues. Since TMTF signal involves envelope, periodicity and fine structure, TMTF assessment would help in understanding the ability of the individual in perceiving the amplitude variation in continuous speech. To address this issue (a) TMTF function across different frequency modulation rates in individual with learning disability and individual with normal hearing, (b) age related changes in TMTF perception at different modulation rates in individual with normal hearing and children with learning disability, (c) comparison of phoneme recognition scores in the presence of noise between the normal hearing individual and individual with learning disability and (d) the correlation between TMTF perception and phoneme recognition scores in the presence of noise for children with learning disability on 24 individuals with learning disability and 20 normal hearing children were measured. TMTF threshold was obtained at different modulation frequency (fm: 4, 16, 32, 64 & 128 Hz). SPIN scores obtained in noise at 0 dB SNR and without noise in both the groups. TMTF threshold showed higher value for children with learning disability than normal hearing subjects with a peak sensitivity at 16 Hz and 4 Hz in normal and individuals with learning disability respectively. SPIN score showed no significant difference between normal and individuals with learning disability. Results suggest that TMTF is a better predictor of temporal processing deficit.

Key Words: learning disability, temporal modulation transfer function, speech perception.

Introduction

Learning disability is a disorder in the psychological processes involved in understanding or using language, spoken or written, which may manifest in an imperfect ability to listen, think, speak, read, write, spell or do mathematical calculations. The causes of learning disability are unknown and often poorly defined. Children with learning disability have auditory processing disorder which has been experimentally investigated by many studies. Whether these auditory processing deficits are seen only in association with language disorder or as a causal factor is yet to be explored. A majority of studies in the literature report that a subgroup of children with learning disability has auditory processing disorder. Tallal et al., (1996) described a deficit in dyslexics involving processing of brief, rapidly changing auditory stimuli. This basic temporal

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processing impairment underlies their inability to integrate sensory information that conveys rapid succession in the central nervous system.

Natural speech is a complex signal which has variation in frequency and amplitude with respect to time. There are three main temporal features of speech namely envelope, periodicity and fine structure. A number of investigators demonstrated that nearly perfect consonant identification and sentence intelligibility could be achieved with speech stimuli processed only with temporal modulation cues which are as low as 50 Hz. (Shannon, 1992; Drullman et al., 1994). Since TMTF signal involves envelope, periodicity and fine structure, TMTF assessment would help us in understanding ability of individual in perceiving the amplitude variation in continuous speech.

Human auditory system has the capacity to resolve the faster and slower changes in the amplitude, frequency with respect to time. (Separate 'fast' and 'slow' auditory system). Any defects in the development of these two 'fast' and 'slow' auditory system may be related to rapid processing deficits which is common to specific language impairment or individuals with language learning disability. Individuals with learning disability specifically dyslexics are impaired in processing the rapidly varying signals which may affect their speech perception ability in the presence of noisy situation (Tallal, et al., 1996).

TMTF has undergone an extensive research in various populations**.** Normal-hearing listeners' sensitivity to sinusoidal amplitude modulation threshold is relatively independent of modulation frequency upto 50-60 Hz, and decreases progressively at higher modulation frequencies (Viemester, 1979; Bacon & Viemester (1985). For low modulation frequencies (16 Hz), detection is limited by the amplitude resolution of the auditory system rather than its temporal resolution. As the modulation frequency increases beyond 16 Hz temporal resolution starts to have an effect and SAM detection threshold increases.

The severe reduction in sentence intelligibility by degrading the consonant identification were observed in normal hearing individuals when amplitude envelope is low pass filtered (Drullman et al., 1994; Zeng et al., 1999). However, unlike other psychophysical studies TMTF is also affected by developmental changes. The psychophysical function varies with the developmental changes and is applicable to other psychophysical tests. The obtained data normally may not be suitable to all the population across the world. So attempt has been made in the present study to obtain norms for the comparison.

Tallal et al., (1996) and Lorenzi et al, (2000) have used TMTF as tool to assess the temporal processing ability in individual with learning disability and it was assessed at two-modulation frequencies 2 Hz and128 Hz. Based on their study they said that dyslexics exhibit impaired ability to perceive the faster modulation which might be leading to poor speech perception in noise. They measured the ability to process temporal envelope cues in dyslexic children by measuring detection of sinusoidal amplitude modulation thresholds (SAM). Each threshold was measured at slow rates and faster rates at 4 Hz and 128 Hz respectively. Overall SAM thresholds were higher in dyslexics than in normal at both rates. These findings are consistent with Tallal's hypothesis, according to which the speech reading deficits in 35% of dyslexics may be caused by impaired temporal processing which play an important role in speech perception.

Zeng, Kong, Michalewski and Starr (2005) studied TMTF at different rates and obtained different patterns in auditory neuropathy in comparison with normal. There is dearth of information about TMTF approach applied to the individual with learning disability in Indian context and it is not checked at different rates. The purpose of the present study were therefore to perform systematic study using different modulation rates in individuals with learning disability and to see age related changes in TMTF perception. Hence an attempt was made to see the temporal processing ability of learning disability at different modulation frequencies.

Poor speech perception in noise by individual with normal hearing and cochlear hearing loss is mainly attributed to degradation caused by noise in processing the low modulation frequency of the speech signal (Noordhock et al., 1997). From the literature it can be understood that poor speech perception may be caused when processing of the temporal modulation in the speech signal is impaired. It has been reported in the literature that dyslexic and individuals with language delay have poor perception in presence of noise (Sandeep & Vanaja, 2004). Hence the present study was conducted to investigate phoneme perception ability of different LD in presence of noise and correlate with TMTF thresholds.

The present study was taken up with the aim to know the: (a) TMTF function across different frequency modulation rates in children with learning disability having normal hearing and children with normal hearing without learning disability. (b) Age related changes in TMTF perception at different modulation rates in children with normal hearing without learning disability and children with learning disability having normal hearing. (c) Comparison of phoneme recognition scores in the presence of noise between the normal hearing and children with learning disability. (d) The correlation between TMTF perception and phoneme recognition scores in the presence of noise for children with learning disability.

Method

Subjects consisted of 24 children with learning disability (age ranging from 8 to 15 years) and 21 subjects with normal hearing (age ranging from 8 to 15 years) who formed the clinical and control group respectively. All the subjects from both the groups underwent hearing evaluation to rule out the hearing loss by routine clinical hearing evaluation. Pure tone audiometry was conducted using modified Hughson-Westlake procedure (Carhart & Jerger,1959) and the threshold were obtained at octaves frequencies from 250 Hz to 8 KHz using clinical diagnostic audiometer (OB 922) under TDH 39 head phones.

Speech identification scores were obtained by conducting speech audiometry using clinical diagnostic audiometer (OB 922) under TDH 39 head phones for each ear independently. Phonetically balanced words developed by Mayadevi (1978) were presented monaurally at 40 dBSL or at most comfortable level and speech recognition score was calculated for 100 percentages.

Normal middle ear function was assesed using GSI-Tympstar immittance audiometer. Each ear was tested separately by placing an airtight probe tip with 226 Hz probe tone and responses were taken. Similarly stapedial acoustic reflexes were measured at 4 frequencies (500 1 K, 2 K & 4 KHz).

All the subjects in the clinical group had poor scholastic performance in reading, writing and calculation. These subjects were assessed by experienced speech-language pathologist and psychologist by using standardized tests materials. Learning Disability was diagnosed by using "Early Reading Skills" developed by Rae and Potter in 1981 which assesses the ability in terms of Alphabet test, Visual and auditory discrimination, Phoneme-Grapheme discrimination, Structural analysis test and reading skills. Psychologist diagnosed the child to have learning disability based on general assessment and detailed case history to obtain with reference to reading, writing, calculation, phoneme-grapheme analysis. All the subjects had undergone APD tests such as dichotic digit test, dichotic consonant vowel test and also speech in noise test. Majority of them showed poor scores in the APD tests administered. The selection criteria are as follows for both groups:

Control group

Subject selection criteria:

1. All the subjects had pure tone thresholds within 15 dBHL
2. Speech identification scores of more than 90% in quite
3. Speech identification scores in noise (0 dB SNR) were better than 80%
4. All of them had 'A' type tympanogram with presence of acoustic reflexes
5. No history of any other problems such as otological and neurological problems
6. The subjects were native speakers of Kannada and English was the medium of instruction

Clinical group

Subjects selection criteria

1. All the subjects had pure tone thresholds within 15dBHL
2. Speech identification scores was better than 90% in quite condition
3. All of them had 'A' type tympanogram with reflexes present.
4. They were native speakers of Kannada and English was the medium of instruction
5. All of them were free of retardation, autism, brain damage or any other psycho-physical dysfunction which was ruled out by experienced psychologist and speech language pathologist and also by detailed case history taken from the parents and school teachers.
6. All of them were diagnosed to have learning disability by experienced speech language pathologist and psychologist

The clinical group and control group was further divided into four subgroups based on their age. Subgroup 1 consisted of 7 normal hearing children without learning disability and 6 children with learning disability in the age range of 8 to 8 year 11 months. Subgroup 2 consisted of 3 normal hearing children without learning disability and 9 children with learning disability of subjects in the age range of 9 to 9 year 11 months. Subgroup 3 consisted of 8 normal hearing children without learning disability and 4 individual with learning disability number of subjects in the age range of 10 years to 10 year 11 months. Subgroup 4 consisted of 3 normal hearing children without learning disability and 5 children with learning disability in the age range of 11 years to 11.11 months.

The following instruments were used for the experiment:

- A computer with "speech editing software" was used to generate the TMTF signal.
- A calibrated 2 channel diagnostic audiometer (orbiter 922). To route the TMTF signal to check for the temporal processing ability and to obtain speech identification scores in quiet and in noise condition. Speech identification score in noise was obtained at 0dB SNR

Experiment was conducted in two phases, they were:

Test stimuli

The stimuli consisted of unmodulated and sinusoidally amplitude modulated (SAM) white noise of 500 ms with a ramp of 10 ms. The modulated signal was derived by multiplying the white noise by a dc-shifted sine wave. The depth of modulation was controlled by varying the amplitude of modulating sine wave. The expression given below to generate the modulated noise;

$$m(t) = [1 + m(\sin 2\pi f_m t)] * n(t)$$

Where m is the modulation depth ($0<m<1$), *fm* is the modulation frequency (2, 4, 8, 16, 32, 64, 128, 256, 512 Hz) and n (t) is the white noise. Stimuli were low pass filtered at 20 KHz. All the stimuli were generated using a 32 bit digital to analog converter at a sampling frequency of 44.1 KHz.

Procedure adapted to establish TMTF threshold:

Subjects were instructed to discriminate the presence of SAM applied to a white noise carrier. On each trail a standard and a target stimulus were successively presented in random order to the listener. The standard consisted of white noise n (t). In the target a white noise carrier was sinusoidally amplitude modulated at a given modulation frequency.

SAM- detection thresholds were obtained using an adaptive two-interval, two-alternative forced-choice (2I, 2AFC) procedure that estimates the modulation depth 'm'. During one of the two 500 ms observation intervals continous wideband noise was sinusoidally modulated. The observer was to discriminate amplitude modulated noise and unmodulated noise. The step size and threshold were based on the modulation depths in decibels (Am=20 log m). The amplitude of the modulation was varied according to the following role: 'Am' decreased 3 dB following a correct response and 'Am' increased 3 dB following an incorrect response to obtain the threshold. The lowest 'Am' at which modulation is detected was considered as threshold. The lowest threshold that can be measured is 0 dB which corresponds to modulation depth of 1 (100% modulated noise).

The testing was conducted in sound treated room where noise level was within permissible limits (ANSI-1996). All the stimuli were presented at 40 dB SL. The stimuli were played from a computer, routed through an audiometer (OB-922) and presented through a loud speaker which was placed 1 meter away from the subjects at an angle of 0 degree azimuth. The presentation level was changed in all the subjects at least at one modulation frequency and modulation detection threshold to ensure that subjects were not using loudness judgments.

The second phase of the study included phoneme perception in the presence and absence of noise. Subjects were instructed to repeat the phoneme which was heard by them. Speech material was presented live through the orbiter 922 clinical audiometer. Stimuli were presented at 40 dB SL or at the comfortable level through the headphones.

Open set phoneme recognition paradigm was used in which listener had to listen to each phoneme tokens and had to say back in a proper order in quiet condition. Further more, same speech stimulus was presented monaurally in the presence of noise at 0 dB SNR. Order of the presentation of the test material was randomized between the conditions for the same subjects to avoid practice effect. Then the correct response obtained was calculated for 100%.

Results and Discussion

The obtained data was statically analyzed using SPSS (version 15) software and results are discussed separately using statistical values.

A. Detection threshold of sinusoidal amplitude modulation:

The following graph shows the TMTF threshold obtained in both control and clinical group along with standard deviations.

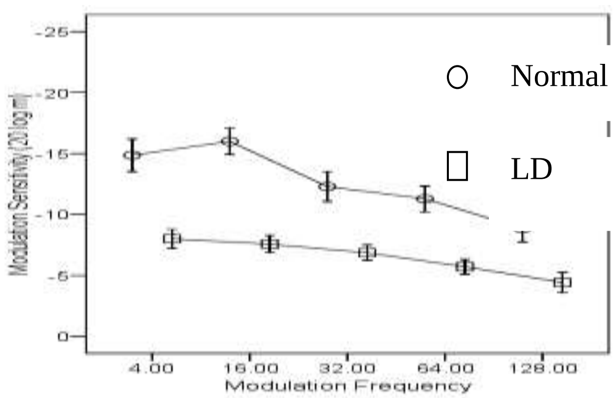

Figure1: Mean TMTF thresholds along with standard deviations at different modulation rates for individual with normal hearing without learning disability and children with learning disability without hearing loss.

It can be seen in the figure that normal hearing subjects display a typical low-pass characteristic i.e. hearing is most sensitive to slow modulation signal but becomes less sensitive as the modulation frequency increases having peak sensitivity at 16 Hz. A similar trend of typical low-pass characteristic was also displayed in children with learning disability subjects. However, they showed much broader response pattern and having peak sensitivity at 4 Hz.

Table 1: Post-Hoc test results of different modulation frequencies for children with LD and with normal hearing

Modulation Frequency	Number of subjects	Subtest	
		2	1
4.00	21	-10.57	-
16.00	21	-10.14	-
32.00	21	-9.57	-
64.00	21	-7.92	-7.92
128.00	21	-	-5.78
Sig	-	.146*	.338*

* $p < 0.01$

A repeated measure ANOVA was performed to assess the significant difference in mean thresholds between two groups at all modulation frequencies. The analysis showed a significant main effect between groups [F (1,100=7.65, P<0.01]. No significant interaction between groups and modulation frequencies [p (4,100) =1.18, P<0.01] were observed. The Scheffe's Post Hoc analysis of variance was carried between the groups across the modulation rates. The results indicate significant difference between TMTF threshold at 128 Hz modulation frequency from 4, 16 and 32 Hz TMTF thresholds. However, no significant difference between 64 Hz and 128 Hz thresholds for both the groups was observed.

The normal hearing subjects had significantly lower TMTF thresholds. SAM-detection thresholds were relatively constant up to 16 Hz but reduced gradually beyond 16 Hz as the modulation frequency increased. Bacon and Viemester, (1985) also observed similar changes in their study. This may be because the individuals with normal hearing show significantly larger physiological response to 'Am' with respect to variation in signal which will be in synchrony of neural fibers to modulation (McAnally & Stein, 1997). Children with learning disability had significantly higher thresholds to amplitude modulation depth than did the normal hearing subjects. The difference in TMTF performance between two groups could be because the individuals with learning disability show significantly smaller physiological responses to amplitude modulated signal than those with normal hearing since they require more synchronous firing of neurons (McAnally & Stein, 1997). As the modulation frequency increases the amplitude fluctuations become extremely smoothened and the observer thus required greater amplitude change in order to resolve the fluctuations (Viemester, 1979) resulting in increase in TMTF threshold in both the groups.

Poor performance by individuals with learning disability is likely to reflect a true defect in 'Am' sensitivity rather than their difficulty in performing the task as shown by previous authors (McAnally & Stein, 1997). They did electrophysiological study in which dyslexic children also had significantly smaller physiological response to 'Am' than control group subjects where they concluded that this may be because of loss of synchrony of neural response to modulation. This resulted in higher sinusoidal amplitude modulation thresholds in individuals with learning disability.

The TMTF for individuals with learning disability was similar to that previously described by McAnally & Stein, (1997); Lorenzi et al. (2000). Threshold obtained in this study was higher at each modulation frequency. This variation in the thresholds may be accounted to the procedural difference used to elicit the response whether it is an identification (Lorenzi et al., 2000) rather than discrimination task.

B. Age related changes in TMTF perception in normal hearing subjects and children with learning disability across the age

It is evident from the table that as the age increases TMTF threshold decreases. However, there is no significant difference seen in TMTF threshold across the age. This pattern was observed in both normal hearing and learning disability group.

Table 2: The mean TMTF thresholds at each frequency along with SD for different age group

Rate / Age		Normal Subjects TMTF					Learning Disability Subjects TMTF				
		4 Hz	16 Hz	32 Hz	64 Hz	128 HZ	4 Hz	16 Hz	32 Hz	64 Hz	128 Hz
8 - 8.11 N=7, LD=6	M	-17.5	-17.0	-13.28	-12.0	-9.8	-3.5	-3.5	-6.0	-6.5	-3.5
	SD	2.07	2.4	1.6	2.4	8.2	6.1	6.1	0	1.2	5.1
9 - 9.11 N=3, LD=9	M	-17.0	-15.0	-14.0	-4.0	-9.0	-8.0	-7.6	-7.3	-6.5	-3.6
	SD	1.7	3.0	3.4	3.0	8.0	1.5	1.5	1.5	1.2	1.3
10-10.11 N=8, LD=4	M	-15.85	-12.85	-11.14	-10.71	-9.42	-8.25	-6.75	-6.0	-4.5	-4.5
	SD	2.1	2.7	3.1	2.2	5.6	1.5	1.5	2.4	1.7	1.7
11-11.11 N=3, LD=5	M	-13.50	-13.50	-12.00	-10.5	-4.50	-7.80	-7.20	-6.6	-4.82	-3.60
	SD	1.7	1.7	1.7	1.6	5.1	1.6	1.6	1.3	1.6	1.3

N- Number of subjects in normal group; LD- Number of subjects in learning disability group

Table 3: Post Hoc test results to see age related changes in TMTF thresholds across modulation frequencies in normal hearing subjects and individual with learning disability

Age	Learning Disability		Normal Hearing	
	N	Subjects	N	Subjects
8.00-8.11	6	-5.400	6	-11.700
9.00-9.11	9	-6.446	9	-11.866
10.00-10.11	4	-6.000	4	-14.250
11.00-11.11	5	-6.000	2	-12.300
Sig		0.537^{+}		0.160^{+}

$^{+}$ Not significant

In the present study psychophysical test TMTF perception was compared using mixed analysis of variance to see developmental changes in TMTF modulation depth performance. Analysis showed that there was no significant difference within subgroup of either control or clinical groups at each frequency. The significant difference is not seen in this study because the age range selected was higher and temporal processing maturation might have been complete by 12 years of age. However it also depends on what type of temporal processing tasks are involved (Chermak & Musiek 1997).

Hall and Grose, (1994) felt that time constant across all age group was interpreted as indicating that the peripheral encoding of the temporal envelope is probably adult like in children aged 4 years and above based on their test results. However young children appear to be relatively inefficient in processing the information underlying modulation detection. In this study similar trend is not seen because of selected age range being much higher. Hence TMTF maturation might have completed much earlier and reached adult like response.

C. Comparison of speech perception ability in the presence of noise between the normal hearing subjects and children with learning disability:

The speech perception scores obtained at 0 dB SNR in normal hearing subjects were better than the scores obtained in individuals with learning disability. There was no significant difference between SIS scores of left and right ear in both the groups. Hence the scores were combined to compare the performance between normal hearing subjects and children with learning disability. Analysis was done using paired sample t-test to know the significance difference if any between the ears and independent samples t-test between the groups.

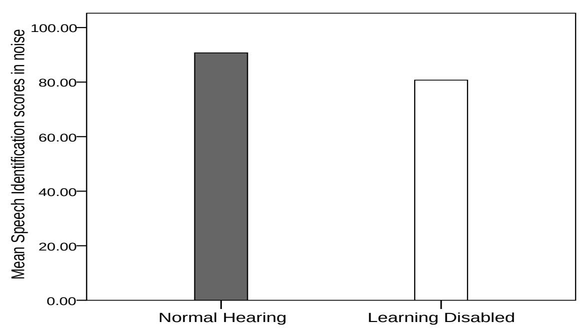

Figure 2: Speech identification scores in noise obtained in children with normal hearing and learning disability

Results showed that there was no significant difference in the performance between the groups in right ear [t=3.07, P<0.01] and left ear [t=3.2, P<0.01]. Similar kind of performance was also obtained by earlier studies by Ferre and Wilber (1986). They reported that an individual with learning disability shows poor performance in CAPD tests including speech in noise test. Lorenzi et al (2000) obtained unprocessed speech signal and speech envelope noise signal identification and observed that individual with dyslexia exhibit poor performance in processing the speech envelope noise when compared to normal hearing subjects. However in the present study few children with learning disability had showed equal performance to that of normal hearing subjects. This might be because all children with learning disability may not exhibit auditory processing problem.

Speech is a complex signal which has variation in its amplitude and frequency of the spectrum (temporal envelope). Presence of background noise will mask the variations in frequency and amplitude of the signal and the signal becomes less redundant to be processed. Chermak and Musiek (1997) reported that the individuals with normal auditory system will be able to process selectively to speech spectrum by ignoring the background noise whereas an individual with auditory processing problem will fail to extract the information from the complex signal. Thus this might have resulted in poor speech recognition scores in the presence of noise in learning disability group.

D. Correlation between TMTF perception and phoneme recognition in the presence of noise obtained from individual with learning disability:

In the present study to see the correlation between SPIN scores and TMTF thresholds peak sensitivity was calculated for the lowest threshold across modulation frequency which in turn correlated with SPIN scores in children with learning disability. To obtain correlation between these two variables Pearson's product moment correlation was used to analyze the data. The analyses showed that there is a significant correlation between these two variables ($r = -0.39$, $P<0.01$). However, a few subjects showed better performance in SPIN scores equal to that of normal. This may be because speech in noise test is less sensitive and less reliable tool in assessing auditory processing deficits (Chermak & Musiek (1997). Results obtained in the current study reveals that TMTF is a sensitive test to assess temporal processing ability than the speech in noise test, to differentiate processing problem that may be auditory based rather than linguistic based. However until now there is no study reported regarding correlation between TMTF and speech perception in the presence of noise.

Conclusion

From the above discussion it can be concluded that learning disability required higher modulation depth to perceive the modulation than the normal group. The peak sensitivity for normal hearing children is higher than for children with learning disability. SPIN scores are likely to be poorer for learning disability than normal group, thus suggesting temporal processing deficit in learning disability. TMTF could be better test to assess temporal processing than SPIN. Data obtained in normal hearing group at different modulation rates can be used as a normative data (as shown in fig 1).

Clinical implication:

1. TMTF is an effective, non invasive, quick and sensitive tool which helps to identify temporal processing disorder, especially in individuals with learning disabilities.
2. TMTF performance in combination with SPIN scores gives a better idea about whether the processing problem is linguistic- based or auditory- based problem.
3. TMTF perception indirectly assesses how well an individual can perceive speech
4. Early indication to diagnosis at risk of learning disability
5. Also can be used in rehabilitation

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