COMPLIMENTARY SPECIALIZATION IN AUDITORY PROCESSING: A PROBE USING MMN

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Dedicated to

My teachers

&

Classmates

CERTIFICATE

This is to certify that this dissertation entitled **"COMPLIMENTARY** SPECIALIZATION IN AUDITORY PROCESSING: A PROBE **USING MMN** " is a bonafide work in part of fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No.MSHM0119)

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CERTIFICATE

This is to certify that this dissertation entitled "COMPLIMENTARY **SPECIALIZATION IN AUDITORY PROCESSING: A PROBE** USING MMN" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any diploma or degree.

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DECLARATION

This dissertation entitled **"COMPLIMENTARY SPECIALIZATION IN AUDITORY PROCESSING: A PROBE USING MMN"** is the result of my own study under the guidance of **DR. C.S. VANAJA,** Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and not been submitted in any other University for the award of any degree or diploma.

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Introduction

Speech is the essence of human life. It forms a fascinating subject for researchers from various fields, as speech is a spectacular example of human-specific behavior. It has also been a very challenging subject since no other behavior is quite so complex and difficult to unravel as speech is.

Like any other behavior, speech is also defined and controlled by the brain. Results of over 100 years of study on the neurological process underlying speech, have demonstrated that the left hemisphere in most human beings is dominant for speech and language functions. The credit of "first contribution" in the area of cerebral asymmetry goes to Broca, 1863 (cited in Mc Manus and Bryden, 1991). This opinion has persisted all through these years and several methods have been evolved to investigate the cerebral asymmetry. In general, it is believed that, in most of the right-handed individuals left hemisphere is specialized for speech perception tasks and right hemisphere for music tasks. One of the most interesting technique used in the recent past years to investigate the cerebral asymmetry is auditory evoked potentials (AEPs). It has been observed that AEP amplitude was increased over the left hemisphere as compared to the right hemisphere during verbal tasks) (Callaway and Harris, 1974).

Mismatch Negativity (MMN) is a modality specific, cortical component of AEPs. It reflects automatic, preattentive auditory discrimination, represented as a small negative deflection superimposed on P_2 wave (Lang, et al., 1995). It can be elicited when a single oddball sequence is presented to a passive subject (Naatanen, Simpson and Loveless, 1982, cited in Naatanen, 1995). It is an objective measure and represents the auditory processing on the superior surface of the temporal lobe as the major contributor (Naatanen, 1992).

(M MN reflects neuronal processing of minimal acoustic difference. It can be obtained when the acoustic differences between the standard and deviant stimuli are small enough to be near psychophysical threshold (Sharma, Kraus, McGee, Carrell & Nicol, 1993). It can be obtained in response to change in non speech stimuli (Sams, Paavilainen, Alho & Naatanen, 1985) and to speech stimuli that are just perceptible (Kraus, McGee, Micco and Sharma, 1993). Since origin of MMN is in higher auditory centres, it could provide useful information about both speech and non speech processing at the cortical level depending on the type of stimulus used.

Studies of the neurophysiological representation of acoustic stimuli have demonstrated that stimuli with complex speech-like acoustic properties including rapid spectro temporal changes, yield greater activation in auditory cortex over the left hemispere (Belin et al., 1998, cited in Bellis, Nicol & Kraus, 2000) and single stimulus parameter over right hemisphere (Levanen, Ahonen, Hari, McEvoy & Sams 1996).

Thus, in the last two decades, MMN has been an interesting tool to compare and study the auditory processing in the two cerebral hemispheres for different tasks.

By the classical view it can be hypothesized that, for the speech stimuli, MMN should be better in left hemisphere than right hemisphere and viceversa for tonal stimuli.

Need for the study

A review of literature related to MMN reveals, studies for both supporting and contradicting the complimentary specialization in speech and non speech processing. There is dearth of literature found regarding the gender and ear effects on MMN responses from two hemispheres. Also, Geshwind and Galaburda (1985) have stated in the cerebral dominance theory that many disorders including stuttering, (dyslexia and autism are the result of delay in left hemisphere growth during fetal development! and consequently right dominance for speech and language. If the notion of complimentary specialization is true with MMN, it can be an interesting noninvasive technique for the audiologist to investigate such population. But for this to be done we need to have a comprehensive data on normal population.)

Hence the present study aimed at the following:

1. To investigate the effect of electrode site on peak amplitude and latency of MMN.
2. To investigate the effect of stimulus type on peak amplitude and latency of MMN.
3. To investigate the effect of stimulus ear on peak amplitude and latency of MMN.
4. To investigate the effect of gender on peak amplitude and latency of MMN.

Review Of Literature

Cerebral dominance until about 35 years ago usually referred to the language mediation of the left hemisphere along with a salient or minor right hemisphere. More recently, neuropsychological research has produced a concept of bilateral function with each hemisphere specialized for different forms of information processing, termed complementary specialization (Bryden, 1990). With reference to one particular function there seems to be an asymmetry between two cerebral hemispheres.

The cerebral asymmetry seen in the processing could be due to the structural asymmetry. Wada, Clarke and Pallie (1975) studied infant and adult brains and found that left temporal planum was larger than the right in the majority of adults and infants.

The functional asymmetry between the two hemispheres can be investigated through different methods. They include the following:

1. Handedness
2. Dichotic CV test
3. Tachistoscopic studies
4. Cerebral blood flow
5. Wada test
6. Auditory Evoked Potentials.

Handedness

This is one of the simplest way of predicting cerebral dominance. In a study by Kertesz, Polk, Black and Howell (1992), 100% of their right-handed subjects showed left hemisphere dominance for speech and language and 100% of left handed subjects showed right hemisphere dominance for speech and language. Right hemisphere was found to process non-speech stimuli and supra segments of speech. But, this method has not been found to be very reliable. Controversy exists since, some of the right-handed individuals also have been shown to possess right hemisphere dominance for speech and language (McManus and Bryden, 1991). If along with the handedness, one considers legedness, eyedness and earedness also, it can become a better indicator of cerebral laterality.

Dichotic Listening Tests

A well-established inferential means of determining hemispheric specialization is the dichotic listening technique (Berlin and Lowe, 1972; Kimura, 1961). The technique consists of presentation of two different stimuli in each ear. Generally when confronted with dichotically presented linguistic stimuli, normal right handed subjects indicated a right ear preference which suggest a left hemisphere specialization for linguistic stimuli whereas, for non-linguistic stimuli, right hemisphere specialization was indicated (Knox and Kimura, 1970).

Kertesz, Polk, Black and Howell (1992) used stop consonant-vowel pairs presented over four blocks of 30 test trials to find the cerebral dominance for speech and language. Results suggested that, (66% of the males, 80% of the females), 71% of right handers and 74% of the left handers were left hemisphere dominant?)

Tachistoscopic studies

Some investigators have used a tachistocopically presented visual stimuli (Hines, 1972; Mckeever and Huling, 1971; Moore, 1976; Kertesz et al., 1992). These studies show a right visual field preference for linguistic materials in normal speaking subjects indicating left hemisphere processing and left visual field preference for non-linguistic stimuli (Visuo-spatial tasks) suggesting a right hemisphere advantage.

Wada Test

This is one of the oldest methods of studying hemispheric specialization. In this technique, one of the hemisphere is temporarily anaesthesized by injecting sodium amytol into the internal carotid artery (Sperry, 1994). This technique typically results in a transient aphasia if one hemisphere that specializes in linguistic processing (usually left) is temporally anasthesized. Milner, Branch and Rasmussen,(1964, Cited in Sperry, 1994), using the Wada test showed that of 48 right handed adults, 90% were left hemisphere dominant for language, none was bilateral and 10% had language represented in right hemisphere.

Cortical blood flow

Using skin temperature over the ophthalmic branches of the internal carotid arteries as indexes of blood flow to the two sides of the head, Dabbs and Choo (1980) found that cerebral asymmetry as indicated by side of blood flow is related to handedness. It has been found that among right handed subjects right side of the brain has more blood flow and higher blood pressure. Their findings indicated that more blood goes to the nonverbal side of the head and suggest that spatial mental functions involve slightly more blood flow than verbal functions.

Auditory evoked potentials

This is one of the interesting, techniques that can be used by the audiologists to investigate the cerebral asymmetry. Studies have shown that AEP amplitude was increased over the left hemisphere as compared to the right hemisphere during verbal tasks (McCallaway and Harris, 1974). But, the event related Ni component arising at the level of the supratemporal plane is assumed to reflect the detection of single acoustic features such a signal periodicity (Naatanen and Winkler, 1999 cited in Hertrich, Mathiak, Lutzenberger and Ackermann, 2002). Hence, may not be reliable, while using speech stimuli, which is a complex of many features. Neural activity within the MMN/MMF domain portrays the earliest representation stage of auditory input. Among others, thus, MMN appears to represent a correlate of "Language-specific phonetic traces" that serve as recognition models for speech sound during auditory perception (Naatanen, 2001).

MMN, originally described in 1975 by Naatanen and colleagues (Naatanen and Gaillard and Mantysala, 1978) is elicited by infrequent changes in a sequence of a repetitive auditory stimulus (Winkler, Tervaniemi and Naatanen, 1997). This negative AEP wave is usually seen as an increased negativity in the latency region following the peak of N_1 and during P_2, usually peaking 100 to 300 ms following stimulus onset. It may be seen as an enlarged N|, a second negative peak or an attenuation of the P_2 wave (Picton, 1990). The MMN is usually best visualized in difference waveform.

In humans, evoked potentials and magneto encephalographic (MEG) studies utilizing tonal stimuli point to the existence of two major sources for the MMN - Supratemporal plane and frontal cortex (Giard et al., 1990). In addition, intracranial recording in the cat suggest that the MMN may receive contributions from thalamus and hippocampus (Czepe et al., 1987 cited in Stapells, 2002).

The MMN reflects central code of stimulus change; its amplitude and latency, are related to the degree to which the deviant stimuli differ from the standard stimuli, not the absolute levels of the deviant / standard stimuli (Stapells, 2002). It can be elicited by frequency, intensity, duration, spatial or phonemic changes (Kraus et al., 1993a, Naatanen, 1990). Generally, the larger the acoustic differences, the earlier and larger is the MMN although there may be ceiling effects in amplitude with large differences (Picton, Alain, Otten, Ritter and Archim 2000).

Deouell and Bentin (1998) compared the amplitude, latency and spatial distribution of the MMN elicited by tones deviating in frequency, intensity, stimulus onset asynchrony or location. They noted that MMN elicited by frequency deviance was larger, and the MMN elicited by stimulus onset asynchrony deviance was earlier than the other two types of MMN.

MMNs have also been recorded for speech stimuli, including vowel and consonant-vowel syllables (Stapells, 2002). MMN appears to reflect acoustic rather than phonetic difference (Sharma et al., 1993). Jaramillo, Alku and Paavilainn (in press) recorded MMN for duration changes in speech and non-speech sounds. Tones and vowels were used as the stimuli. Results confirmed that the degree to which stimuli are 'speech like' determines how duration changes are processed.

Irrespective of the degree of deviance, MMN responses are dependent on certain other factors. As the stimulus level is lowered, if the degree of deviance is held constant, MMN amplitudes decrease and latencies increase (Schroger, 1996). This is likely the result of fewer cortical neurons overall being involved in response to the two stimuli when intensity is decreased (Stapells, 2002). Short-term memory is another factor that influences the MMN (Cowan, Winkler, Tedes and Naatanen, 1993).

Literature reveals variable findings regarding the effect of gender on MMN responses. Barrett and Fulfs, 1998 used frequency deviance as the parameter to record responses from Cz and Fz. Results showed no significant differences in peak latency of MMN responses between males and females have been seen, although peak to peak amplitude and duration was significantly larger in women. Aaltonen, Erola, Lang, Vusiparkka and Toomainen (1994) used speech stimuli and recorded responses from CI, C2, Cz, and F_z for adult males and females. Results showed significant longer latency of MMN in females than in males. However, in terms of amplitude no significant difference between the two groups was seen.

Ear of stimulation is another factor on which MMN depends. Lavikainen, Tiitinen, May and Naatanen (1997) through their study concluded that the MMN elicited by binaural stimulation is larger than that with monaural stimulation. Subjects were presented with monaural and binaural stimulus trains consisting of frequent standard stimuli and deviant stimuli deviating from the standard either in frequency, intensity or duration. (MMN for the intensity change was larger with binaural than monaural stimulation, whereas for the frequency and duraton change, the MMN amplitude remained unchanged. Thus, cortical interaction reflected summation in the MMN elicited by intensity deviation and occlusion for the frequency and duration deviation.

Deouell, Bentin and Giard (1998) studied the characteristics of MMN elicited by dichotic stimulation examined using frequency deviant stimuli presented to the right, to the left or to both sides. The experiment was run twice, once using earphones and once using loudspeaker in the free field. MMNs were recorded from F_z, F3, F4, Ml, M2 and Cz electrode sites. Results showed that, for stimulation presentation through earphones amplitude of the MMN was bigger at the frontal lateral right hemisphere sites than at the homologous left hemisphere sites for all deviance conditions. Scalp current density analysis revealed that deviance in the right side elicited bilaterally equivalent frontal current sinks and a trend towards stronger contralateral current sources at the mastoid sites. In contrast, left side deviance elicited frontal sinks and temporal current sources stronger over the right hemi scalp. The authors concluded that the results are compatible with the multiple generators model of MMN.

Many studies have been conducted to find the generators of MMN. Potts, Dien, Hartry-Speiser, McDougal and Tucker, (1998) used a 64 channel recording array and spherical spline interpolation to find the scalp distributions of event related potentials in an auditory oddball paradigm. Frequent and infrequent tones differing in terms of frequency were presented to normal right-handed individuals in passive and active task blocks. ANOVAs and topographic analyses were performed on the primary deflections in the in the late portion of the event related potential: PI, Nl, P2, N2, and P3. A target minus standard difference wave was also created for each task. The difference wave contained a MMN; The MMN did not differ between the passive and active tasks. The scalp distribution was consistent with generation in frontal and superior temporal cortex, suggesting activity in cortical areas of selective attention and auditory stimulus representation.

However the studies using different scalp distribution to find the generators of MMN have found an asymmetry in the MMN from two cerebral hemispheres. Giard, Perrin, Pernier, & Bouchet (1990) applied current source density analysis to MMN difference wave topographic maps. MMNs was recorded to the rare stimuli deviating in pitch. Results showed that, in all cases, the negative wave elicited by the deviant stimuli showed the highest amplitudes over the right hemiscalp irrespective of the ear of stimulation. This was attributed to the sum of activities of two set of neural generators: one temporal, located in the vicinity of the primary auditory cortex, predominantly activated in the hemisphere contralateral to the ear of stimulation and the other frontal, involving mainly the right hemisphere. Levanen, Ahonen, Hari, McEvoy and Sams (1996) investigated whether mismatch field (MMFs) would reveal hemispheric differences in cortical auditory processing. MMFs of seven healthy adults recorded for the stimuli differing in frequency, duration or interstimulus interval revealed stronger involvement of the right than the left hemisphere in change detection.

Rinne, Alho, Alku, Holi, Sinkkonen, Vertanen and Bertrand (1999) used dense electrode array covering the whole scalp to record the MMN, automatically elicited by occasional changes in sounds, which ranged from non phonetic (tones) to phonetic (vowels). Results showed that speech processing occurs predominantly in the left hemisphere. On the contrary Hertrich, et al. (2002) reported right lateralized early MMF component emerged in response to natural syllables during pre attentive processing. Also Naatanen and Michie (1979, cited in Picton, 1995) found that the auditory cortex component was bilateral but larger in contralateral than ipsilaterally to the ear stimulated. So, the MMN should be dominant in the contralateral hemisphere to the stimulated ear irrespective of the type of stimulus presented.

Thus, the literature of MMN reveals an equivocal opinion regarding complimentary specialization of MMN, necessitating for the present study.

Method

The following method was adopted to experimentally investigate the effect of electrode site, stimulus type, ear of stimulation and gender on MMN responses.

Subjects

Twenty-four normal hearing adults in the age range of 17-24 years participated in the study. The twenty-four subjects included 13 males and 11 females who passed the following selection criteria:

1. No history of any relevant neurological or audiological disorders.
2. Normal hearing threshold over the frequency range of 250 Hz to 8000 Hz.
3. 'A' type tympanogram with reflexes present.
4. Scored high for left cerebral laterality in laterality preference schedule given by Dean (cited in Venkatesan, 1993. refer Appendix 1 for details).

Instrumentation

1. A calibrated two channel diagnostic audiometer was used for pure tone audiometry.
2. A calibrated middle ear analyzer to assess middle ear function.
3. Intelligent Hearing Systems with Smart EP (version 2.1x) was used to record and analyze the MMN.

Stimulus and recording parameters

Two sets of stimuli were used. One set of tonal stimuli and one set of speech stimuli. The speech stimuli spoken by a normal adult female was recorded into a computer using an unidirectional microphone. The computerized material was normalized using AUDIOLAB Software so that, both the monosyllables are of equal intensity. The wave file was then converted to stimulus file for AEPs using the software "Stimconv" provided by M/S Intelligent hearing systems. Parameters for tonal stimulus were set using the options available in the software.

The parameters used for the recording of MMN using speech and tone bust are as shown in the Table 1

Table 1: Stimulus and recording parameters for MMN

Parameter	Speech MMN	Tone burst MMN
Type of stimulus	Monosyllables Frequent : |da| Infrequent: |ga|	Alternating tone bursts Frequent : 1000Hz Infrequent: 1100 Hz
Intensity	60 dB nHL	60 dB nHL
Stimulus duration	230 msc	230 msec
Maximum No. of Averages infrequent stimuli	100	100
Repetition rate	1.9/sec	1.9/sec
Ratio of Freq : Infreq	5:1	5:1
No. of channels	4	4
Gain	75,000	75,000
Band pass fitter	0.1-300Hz	0.1-300Hz
Recording window	-50msec to 400msec	-50msec to 400msec
Transducer	ER3A Insertphones	ER3A Insertphones

Electrode montage

A

MMN was differentially recorded from FPz, Cz, TL & TR, with forehead as ground and nose tip as the reference electrode placement. TL was located halfway between T_3 and T_5 and TR was located halfway between electrode sites T_4 and T_6.

Test procedure

The subjects who passed all four-selection criteria were included for the experimental procedures. They were seated in a comfortable position to ensure a relaxed posture and minimum muscular artifacts. The subjects were instructed to sit in a relaxed posture and not to pay attention to the auditory stimuli. The skin surface at the fore mentioned sites were cleaned and the silver chloride disc electrodes were placed.

After ensuring the permissible low impedance the data was acquired. The recording of MMN was carried out using the protocol described in Table 1. The following four recordings were carried out for all the subjects.

1. MMN for speech stimuli presented to the right ear.
2. MMN for speech stimuli presented to the left ear.
3. MMN for non-speech stimuli presented to the right ear.
4. MMN for non-speech stimuli presented to the left ear.

The sequence of recording was randomized to avoid the order effect. The total time taken to complete the recording on one subject ranged from 45 minutes to 1 hour.

Analysis of MMN

To determine the latency and the amplitude of MMN for a subject, the patterns of the individual's averaged standard, deviant and difference (deviant minus standard) waveforms were examined. In the difference waveform, MMN was identified using following criteria.

A trough in the latency range of 50-300 msec.

Should be a negative potential of amplitude more than -0.3 µV.

Should occur either in the N_1P_2 or N_2P_2 complex.

- A positive peak should follow the negative peak.

The latency and the amplitudes of MMN recorded from the four different sites were noted. The data obtained was tabulated and statistically analyzed using two-way ANOVA, to see the main effect of variables considered in the study, on MMN.

Results

The mean and standard deviation of latency and amplitude were calculated separately for males and females, right ear V/S left ear, speech V/S tonal stimuli, and across different electrode sites. Two-way ANOVA was done using SPSS (version 10.0.5) software to investigate the aims of the study.

LATENCY OF MMN

The results obtained for latency are discussed under the following heading:

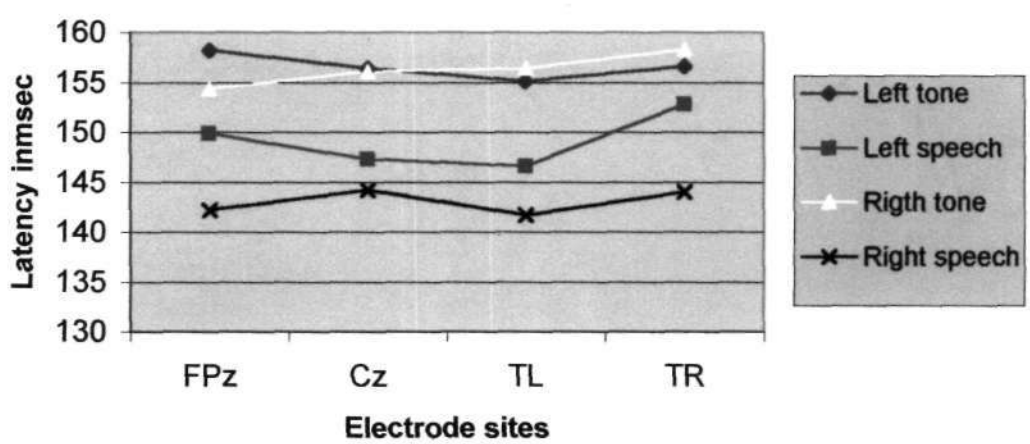
1. Effect of electrode site on latency of MMN.
2. Effect of stimulus type on latency of MMN.
3. Effect of ear of stimulation on latency of MMN.
4. Effect of gender on latency of MMN.

Effect of electrode site on latency of MMN

The mean latency of MMN at four electrode sites, FPz, Cz, T_L & TR were obtained. Table 2 and Graph 1 shows the mean values at each separately for four different experimental conditions. Table 2 also shows the standard deviation values.

Table 2: Mean and Standard deviation values across four electrode sites in four different experimental conditions.

	Sites	M (in msec)	SD (in msec)		Sites	M (in msec)	SD (in msec)
Left Tone	FP_Z	158.21	26.6	Left Speech	FP_Z	149.87	25.78
	C_z	156.41	29.35		C_z	147.31	22.52
	T_L	155.07	27.63		T_L	146.55	21.56
	TR	156.57	29.12		TR	152.08	25
Right Tone	FP_Z	154.33	21.09	Right Speech	FP_Z	142.22	22.47
	Cz	156.04	23		C_z	144.2	20.03
	T_L	156.4	22.6		T_L	141.7	18.08
	TR	158.23	28.6		TR	143.98	20.98



Graph 1: shows the mean latency values across four electrode sites in four experimental conditions

As evident in the table and graph, there was a difference in latency across the sites in all four experimental conditions. When speech stimuli were presented, T_L showed the shortest latency both for right and left ear stimulation. Longest latency was seen at TR for left ear and Cz for right ear stimulation. When the tonal stimuli was used, shortest latency was seen at T_L for left ear and FP_Z for right ear stimulation. Longest latency for left ear and right ear were seen at FPz & T_R respectively.

Two-way ANOVA was done for all four experimental conditions separately, taking ear of stimulation and site of recording as independent variables. Results showed no main effect of electrode site on MMN latency. Also no interaction effect was seen between the two variables.

No single electrode site consistently produced a shorter or longer latency compared to other sites. Inspection of individual data showed the site TR produced longer latency maximum number of times followed by FPz, TL & Cz irrespective of the type & ear of stimulation. Among the TL and TR sites, when speech stimuli were used, 79% of the subjects showed shorter latency at TL, 13% at TR and 8% showed equal latency at T_L and T_R, whereas when tonal stimuli was used, 54% of the individuals showed shorter latency for TR, 33.5% for TL and 12.5% showed equal latency values. Such trend was not seen with other electrode pairs.

Effect of stimulus type on latency of MMN

As shown in Table 2 and Graph 1, when speech stimuli were used, MMN latencies were consistently lower at all electrode sites than that for tonal stimuli. Two-way ANOVA was done for each electrode site separately, considering ear of stimulation and stimulus type as independent variables. Results showed a main effect of stimulus type ($F = 16$, $P < 0.00$) at all the sites except T_R. No interaction effect was seen between the two variables considered. Inspection of the individual data revealed that among the 24 subjects, 66% had shorter latency when speech stimuli were used and 34% when tonal stimuli were used.

Effect of ear of stimulation on latency of MMN

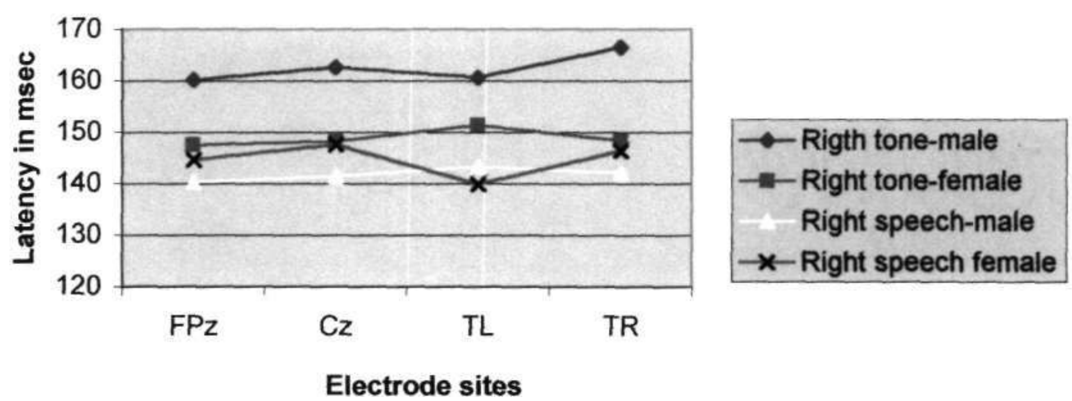
As depicted in Table 2 and Graph 1, the latencies obtained with right ear stimulation were shorter than those with left ear stimulation at all four sites for speech stimuli, whereas, for tonal stimuli, this trend of right ear advantage was seen only for FPz and Cz sites. The latencies obtained at T_L and T_R sites were higher for right ear tonal stimulation. Two-way ANOVA showed no main effect of ear of stimulation at any of the sites. No interaction effect was seen between the ear of stimulation and and stimulus type.

The latencies were shortest when speech stimuli was presented to the right ear. Among the 24 subjects, 58% had shorter latency MMN when the stimulus was delivered through the right ear.

Effect of gender on latency of MMN

Table 3: Mean and standard deviation values of latency for males and females at four electrode sites for right ear stimulation.

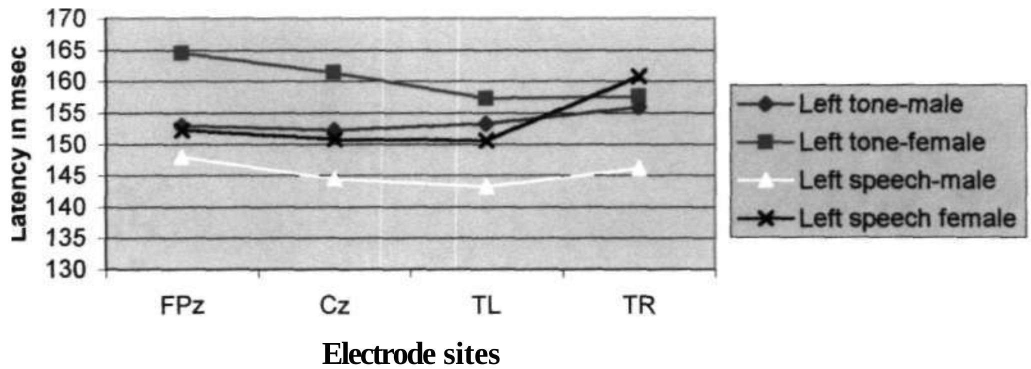
	Male				Female	
	Site	M (in msec)	SD (in msec)		M (in msec)	SD (in msec)
Right ear Tone	FP_Z	160.08	22.68		147.55	17.67
	Q	162.58	24.71		148.31	18.78
	T_L	160.68	28.17		151.34	13.07
	TR	166.55	32.77		148.39	20.12
Right ear Speech	FP_Z	140.19	20.63		144.61	25.28
	C_z	141.35	15.19		147.59	24.96
	T_L	143.22	18.92		139.9	17.76
	TR	142.00	15.65		146.32	25.89



Graph 2: Shows mean latency values across four electrode sites in two experimental conditions for males and females in right ear stimulation.

Table 4: Mean and standard deviation values of latency for males and females at four electrode sites for left stimulation.

	Male				Female	
	Site	M (in msec)	SD (in msec)		M (in msec)	SD (in msec)
Left ear Tone	FP_Z	152.94	28.54		164.45	23.9
	c_z	152.25	35.44		161.34	20.61
	T_L	153.21	34		157.28	18.93
	TR	155.78	33.80		157.51	24.03
Left ear Speech	FP_Z	147.91	22.68		152.19	22.5
	C_z	144.39	24.11		150.76	23.7
	T_L	143.12	28.17		150.6	23.75
	TR	146.09	32.77		160.72	31.12



Graph 3: shows mean latency values across four electrode sites in two experimental conditions for males and females in left ear stimulation.

Inspection of the Table 3, 4 and Graph 2, 3 reveals that for males mean latency across all the four sites were shorter for males than females for speech stimuli in both the ears and for tonal stimuli in the left ear. An opposite trend was seen for right ear tonal stimulation. Two-way ANOVA was done for each experimental condition separately, taking gender and site of recording as independent variables. Results showed a main effect of gender (F = 8.00, P0.01) for right ear tonal stimulation. The effect was not significant for other experimental conditions. No interaction effect was seen between the two variables.

Among the 13 males, 76% had shorter latency at T_L site when speech stimuli were presented. 7.6% showed shorter latency at T_R and rest had equal latency at both the sites. Among 11 females, 82% had shorter latency on left hemisphere and 18% on the right hemisphere.

In response to tonal stimuli, 7 among 13 males showed shorter latency at T_R compared to T_L and 6 among 11 females followed this trend. Right ear advantage was seen in 8 males and 6 females. The trend of latencies being shorter for speech stimuli than tonal stimuli was seen in 10 males and 6 females.

AMPLITUDE OF MMN

The results obtained for amplitude are discussed under the following headings:

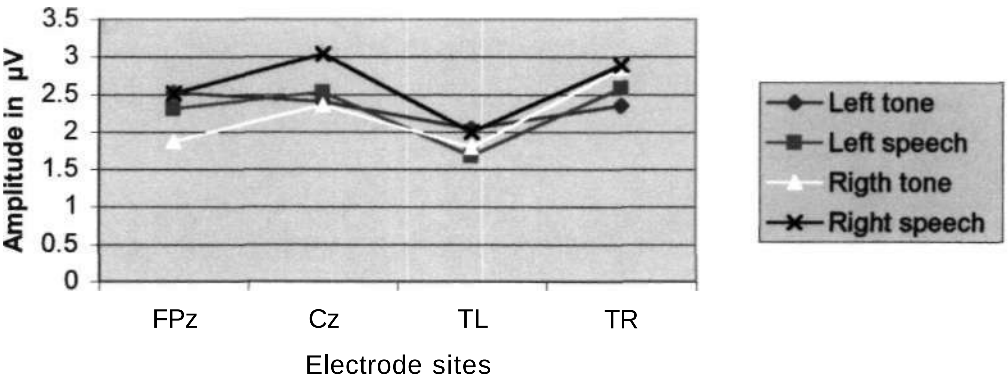
1. Effect of electrode site on amplitude of MMN.
2. Effect of stimulus type on amplitude of MMN.
3. Effect of ear of stimulation on amplitude of MMN.
4. Effect of gender on amplitude of MMN.

Effect of Electrode site on amplitude of MMN

The mean and standard deviation values for amplitude of MMN across different sites were obtained. Table 5 and Graph 4 shows the mean amplitudes recorded. The means are shown separately for speech and tonal stimuli and also for right and left ear. Table 5 shows standard deviation values also.

Table 5: Mean and standard deviation of amplitude values at four electrode sites in four experimental conditions

	Site	M (in µV)	SD (in µV)		Site	M (in µV)	SD (in µV)
Left tone	FP_Z	2.52	1.32	Left speech	FP_Z	2.31	0.89
	C_z	2.40	0.97		C_z	2.53	1.06
	T_L	2.04	0.95		T_L	1.68	0.94
	TR	2.35	0.86		TR	2.58	0.94
Right tone	FP_Z	1.87	0.75	Right speech	FP_Z	2.51	1.06
	C_z	2.36	0.99		Cz	3.04	1.43
	T_L	1.79	0.54		T_L	2.00	0.74
	TR	2.85	0.89		TR	2.89	1.04



Graph 4: shows mean amplitude values at four electrode sites in four experimental conditions

Data indicated that, when speech stimuli were presented, TL showed the smallest amplitude both for right and left ear stimulation. Largest amplitude was seen at C_z for right ear and T_R for left ear stimulation. Similarly, when the tonal stimuli were presented, T_L showed least amplitude both for right ear and left ear stimulation, whereas maximum amplitude was at T_R for right and FP_Z for left ear stimulation. Two way ANOVA was done for tonal and speech stimulation separately, considering electrode site and ear of stimulation as the two independent variables. Results showed a main effect of site of receding [F = 4.84 (tonal), 8.42 (speech), P<0.00] across all the sites. No interaction effect was seen between the two variable considered.

Effect of stimulus type on MMN amplitude

The effect of stimulus type on amplitude of MMN can be observed from Table 5 and Graph 4. Speech stimuli produced consistent higher amplitude compared to tonal stimuli when presented to the right ear. But, during left ear stimulation, for speech stimulus only C_z and T_R had higher amplitude relative to that with tonal stimuli. Two-way ANOVA was done for each ear separately, taking stimulus type and site of recording as the independent variables. Results revealed main effect of stimulus type ($F = 7.18$, $P < 0.00$) for only right ear stimulation. No interaction effect was seen.

Among 24 subjects, only 25% had higher amplitude for speech MMN at all electrode sites and in both the ear. Rest of the subjects did not show any consistent trend at all electrode sites.

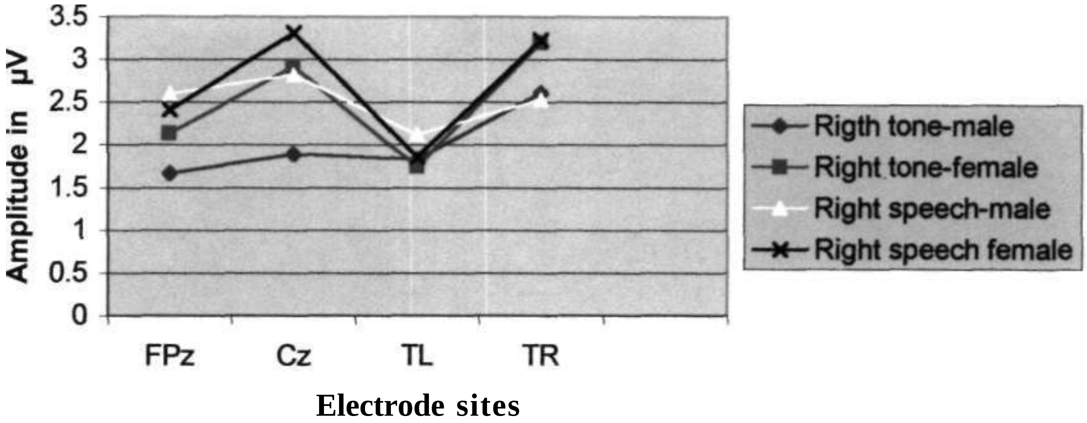
Effect of ear of stimulation on amplitude of MMN

Inspection of Table 5 and Graph 4 reveals that, when the speech stimulus was used, right ear stimulation showed higher amplitude compared to left ear stimulation. A reciprocal trend was seen with the tonal stimuli, except at TR where, right ear stimulation yielded higher amplitude. Two way ANOVA was done for tonal and speech stimulus conditions separately, by taking ear of stimulation and electrode site as the two independent variables. Results revealed a main effect of ear of stimulation ($F= 4.69$, $P < 0.05$) only for speech stimulation. Among the 24 subjects only 29% had higher amplitude MMN when the stimulus was given through right ear.

Effect of gender on amplitude of MMN

Table 6: Mean and standard deviation values of amplitude for males and females at four electrode sites for right ear stimulation.

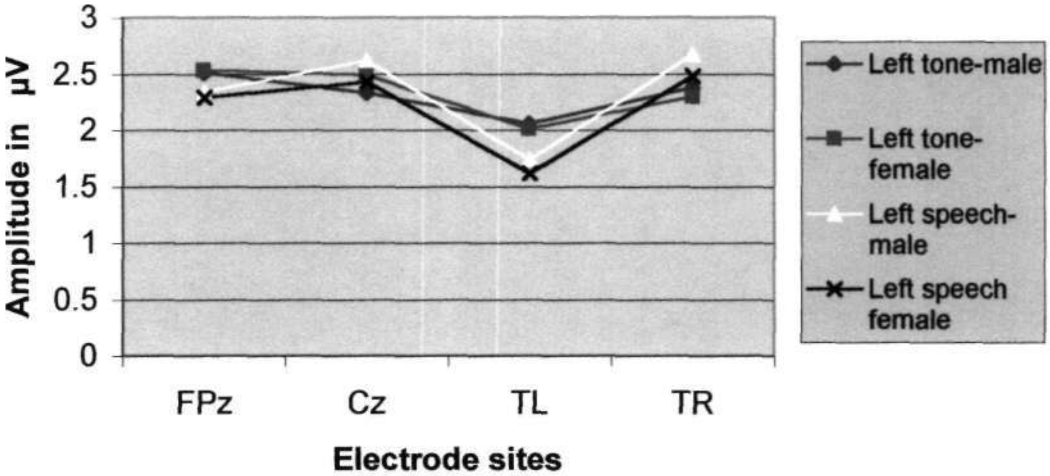
		Male			Female	
	Site	M (in µV)	SD (in µV)		M (in µV)	SD (in µV)
Right ear Tone	FP_Z	1.66	0.52		2.13	0.92
	C_z	1.89	0.85		2.92	0.90
	T_L	1.83	0.57		1.75	0.53
	TR	2.61	0.73		3.2	0.98
Right ear Speech	FP_Z	2.59	1.19		2.41	0.92
	C_z	2.82	1.58		3.31	1.25
	T_L	2.12	0.72		1.86	0.76
	TR	2.53	1.08		3.23	0.9



Graph 5: show mean values of amplitude for males and females at four electrode sites for right ear stimulation.

Table 7: Mean and standard deviation values of amplitude for males and females at four electrode sites for left ear stimulation.

	Male				Female	
	Site	M (in µV)	SD (in µV)		M (in µV)	SD (in µV)
Left ear Tone	FPz	2.51	1.50		2.53	1.13
	C_z	2.33	0.96		2.49	1.02
	T_L	2.06	1.04		2.01	0.89
	TR	2.38	0.77		2.30	0.99
Left ear Speech	FP_Z	2.34	0.95		2.29	0.87
	C_z	2.62	1.16		2.43	0.99
	T_L	1.74	0.86		1.62	1.07
	TR	2.67	1.07		2.48	0.80



Graph 6: show mean values of amplitude for males and females at four electrode sites for left ear stimulation.

As can be seen in Table 6 and Graph 5, females showed higher amplitude at all four sites except at T_L than males, when tonal stimuli was presented to the right ear, whereas no such trend was seen when speech stimulus was delivered to the right ear. Table 7 and Graph 6, males showed higher amplitude at all sites when speech stimuli were presented to the left ear. Such trend was not observed with the other experimental condition. Two way ANOVA was done for each experimental condition separately, by considering gender and site of recording as the independent variables. Results showed no main effect of gender on amplitude of MMN. Also no interaction effect was seen between the two variables.

Among 13 males, 16.6% showed higher amplitude in speech MMN, compared to tonal MMN at all the sites. Among 11 females, 8.44% showed such trend. Right ear advantage was seen in 4 males and 3 females.

Discussion

Results of the present study indicated no significant difference in latency across four different electrode sites. This could be reasoned to the large variability in MMN responses (Kurtzberg, Vaughn, Kreuzer and Fliegler, 1995). The standard deviation obtained in the present study was high and this could have masked the subtle latency differences seen across the sites.

Among the responses recorded from four electrode sites, only sites TL and TR showed a consistent trend. Averaged responses revealed consistent trend of latency being shorter at TL than TR in all four experimental conditions. But, inspection of the individual data showed a difference. Responses were shorter in latency and larger in amplitude at TR compared to that at TL for tone bursts in most of the individuals. Similar relation was seen between speech stimuli and responses at TL. This can be interpreted as the larger right hemisphere activity for tone-bursts and left hemisphere activity for speech. The present finding draws support from the study by Deouell et al., (1998) in which, MMN was bigger at the frontal lateral right hemisphere sites than homologous left hemisphere sites, for frequency deviant stimuli. This suggests that the speech stimuli are processed in the left hemisphere and tonal stimuli in the right hemisphere. This supports the notion of complimentary specialization given by Bryden(1990).

Another finding in the present study to support complimentary specialization is, when the speech stimulus was presented to the right ear, latencies were shorter, but were prolonged relatively when presented in the left ear. Similarly, when the tonal stimulus was presented to the left ear, latencies were shorter but prolonged relatively when presented in the right ear. The results of the present study is in consonance with the study by Rinne et al. (1999), which identified speech processing to be predominantly in the left hemisphere. Results of the investigation by Levanen et al., (1996) and Giard et al., (1990) which revealed right hemisphere dominance for tonal processing, are also in agreement with the present finding.

Among the two types of stimuli used, speech stimuli produced shorter latency and higher amplitude compared to tonal stimuli. This difference might be due to the fact that natural syllables comprise multiple cues and the magnitude of deviance is more among them. Earlier studies using tonal stimuli have concluded that, with increase in the magnitude of deviance the amplitude increases and latency decreases (Jose, 1999; Sams, Paavilainen, Alho and Naatanen, 1985). Giard et al. (cited in Alho, 1995) suggested that MMNs to frequency, intensity and duration changes may be generated by different supratemporal neuronal population. Since, natural speech stimuli used in the present study differed in all three aspects, a larger group of neuronal population participates in the central speech discrimination leading to shorter latency and larger amplitude MMN.

Ear of stimulation showed a significant effect on amplitude. Inspection of the individual data on latency also suggested that, when the speech stimulus was presented to the right ear, left hemisphere activity was earlier in most of the subjects compared to stimulus presentation in the left ear. Similarly, when the tonal stimuli were presented to the left ear, latencies were shorter in the right hemisphere in most subjects compared to presentation in the right ear. Naatanen and Michie (1979, cited in picton, 1995) also found that the auditory cortex component was bilateral but larger contralaterally than ipsilaterally to the ear stimulated. This supports the notion of right ear advantage for speech stimulus and left ear advantage for tonal stimulus. This is because, Contralateral pathways are more numerous or stronger than ipsilateral pathways (Speaks, 1975). Since right ear is directly coupled to the left hemisphere, it takes less time to carry the speech stimuli from right ear to the processing site in the left hemisphere whereas, for tonal stimuli it has to first reach the left hemisphere and then right hemisphere where the processing occurs. By contrast, when the tone burst was presented to the right ear, mean latency values of females showed earlier MMNs at all the sites indicating right ear advantage for tonal stimuli. However the present finding is in contradiction with the results obtained by Deouell et al. (1998). In their study, MMNs were recorded from Fz, F3, F4, Ml, M2 and Cz electrode sites for frequency deviance in dichotic stimulation. Results of scalp current density analysis revealed that deviance in the right side elicited bilaterally equivalent frontal current sources. Discrepancy in results may be due to methodological differences. The present study used monotic presentation, where both frequent and infrequent stimuli were presented to the same ear whereas, Deouell et al. had used dichotic stimulus presentation with deviant stimuli presented to either in left or right ear.

Gender specific findings were observed in the present study. Males showed right ear advantage for speech stimuli and left ear advantage for tonal stimuli whereas, females showed right ear advantage for both speech and tonal stimuli. In general, though not significant, males had shorter latency than females, reflecting gender-specific differences in the processing of signals. Significantly longer latency of MMN for complex stimuli in females than males was also reported by Aaltonen, et al., (1994). There was no significant difference between two genders in terms of amplitude. This finding contradicts with the study by Barret et al., (1998) in which females had significantly larger amplitude MMNs than males. The difference in findings could not be reasoned with the available literature and hence indicates the need for further studies to probe the effect of gender on MMN.

Summary and Conclusions

MMN is a negative component resulting from the difference in event related potential waveforms elicited by a standard and deviant stimulus. It is elicited by any discriminable change in a repetitive sound even when this sound is not attended to. It provides a pre-perceptual physiological measure of the accuracy of the central sound representation in the brain. Generators of MMN have been traced both at the cortical and sub-cortical level.

MMN can be elicited by both speech as well as tonal stimuli. Since it provides the physiological measure of central sound representation, if experimentally proved, it will be a powerful tool for the audiologists to check the classical view of complimentary specialization. That is, to check whether tasks related to verbal items are controlled by left hemisphere and nonverbal items by the right hemisphere.

The asymmetry in MMN elicited by one group of stimuli (speech or tones) has been documented in the literature. But a single study using both speech and tonal stimuli has been in scarce. If comprehensive data on normal population is obtained, further studies can be carried out in deviant population like learning disability and stuttering, where disrupted cerebral dominance has been speculated as the cause of the disorder.

Hence the present study was carried out with the following aims:

1) To investigate the effect of electrode site on latency and amplitude of MMN.
2) To investigate the effect of stimulus type on latency and amplitude of MMN.
3) To investigate the effect of stimulus ear on latency and amplitude of MMN.
4) To investigate the effect of gender on latency and amplitude of MMN.

Twenty-four normal hearing right-handed subjects (13males, 11 females) participated in the present study. MMNs were recorded using speech (/da/ and /ga/) and tonal stimuli (1000 Hz and 1100Hz), presented to right and left ear separately through insert phones. The data was collected using Intelligent Hearing Systems Smart EP (version 2. IX). Responses were recorded from electrode sites, FPz, Cz, TL, TR. The tabulated responses of twenty-four subjects were statistically analyzed in terms of latency and amplitude of MMN using two-way ANOVA.

Results of the present study lead to the following conclusions:

- Left hemisphere activity was more for speech stimulus and right hemisphere activity for tonal stimulus, supporting the notion of complimentary specialization. But this difference was not statistically significant.
- Speech stimulus produced MMNs which were higher in amplitude and significantly lower in latency indicating that, larger the magnitude of difference, better is the processing

- Comparison of the right and left ear stimulation revealed right ear advantage for speech stimuli and left ear advantage for tonal stimuli but this difference was not statistically significant.
- Females had significantly higher left hemisphere activity during tonal processing than males. Males had shorter latency and larger amplitude MMNs than females during speech processing either for right or left ear stimulation and tonal processing for left ear stimulation, suggesting gender specific processing of auditory stimuli.

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Appendix 1

Laterality Preference Schedule, Modified

With which hand would you:

1. Wipe a table with cloth
2. Hold a glass when drinking
3. Put a coin into a box
4. Raise when called out
5. Write
6. Brush teeth
7. Eat
8. Comb or brush hair
9. Open a drawer or dresser
10. Point to objects
11. Pick an object kept on the table
12. Switch on the light
13. Have the greatest strength
14. Hold a pair of scissors for cutting
15. Use first while putting on shirt
16. Erase a pencil mark with eraser
17. Hurl a ball
18. Hold an umbrella while walking

With which foot would you :

19. kick a ball
20. Hop
21. Put on your footwear first
22. Stand the longest
23. Extend first when asked to stand and walk
24. Have the greatest strength

With which eye would you:

25. look through a small hole
26. Aim while hitting a ball
27. See through a tube
28. Spontaneously see when asked to close one eye

With which ear would you:

29. Listen to telephone.
30. Listen to faint sound from distance