Chapter-4

Results and Discussion

RESULTS AND DISCUSSION

The results and discussion pertaining to the current study are presented under three sections. In **Sections 4.1 and 4.2**, the results for the SEABR in different age groups as well as their comparison are presented and discussed. In S**ection 4.3,** the results for the SEABR in first time hearing aid users as well as the comparison of the same with OA is reported and discussed.

The present study was carried out to compare the electrophysiological encoding of speech sounds in three different age groups, namely-Younger Adults (YA), Middle Aged Adults (MA) and Older Aged Adults (OA). The study also secondarily aimed at enhancing its application in clinical groups by considering the first time hearing aid users. Brainstem responses to speech stimuli were recorded using synthetic stimuli /da/. Both Onset Responses (OR) and Sustained Responses (SR) were analyzed in terms of latencies and amplitudes. Mean and SD were obtained for both the parameters. Analysis of variance (ANOVA) was administered to compare the variance between the responses obtained within the three normal hearing groups. Additionally, post analysis of each parameter was done using Bonferonni Post hoc test. Independent 't' test was performed to compare the variances in first time hearing aid (HA) users group with that of OA.

4.1 SEABR in different age groups

The SEABR responses were analyzed separately by the mean latencies and amplitudes of the OR and SR obtained for the syllable /da/ *(Figure:4.1).*The OR of the SEABR included the peaks- V, A, C which represent the transient portion of the response and the cessation of the response, that is Peak O. The peaks D, E and F represented the SR-Frequency Following

Response (FFR). The results obtained for the latencies and amplitudes for the onset (V,A C, O) and sustained (D, E ,F) responses are depicted below.

4.1.1. Latencies of the OR- V, A, C and O.

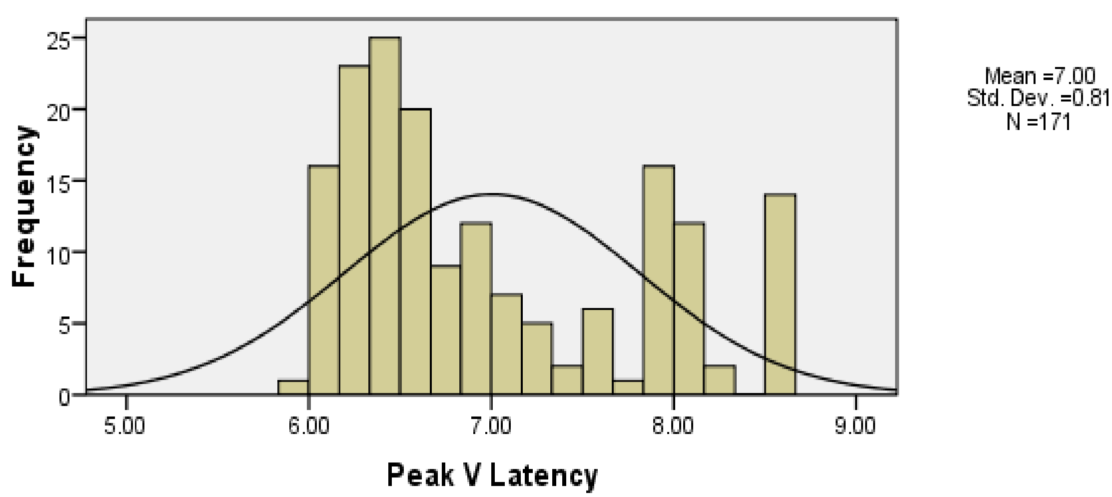
The results of the peaks V, A, C and O are given in Tables 4.1 to 4.4 and graphs 4.1 to 4.4 in each age group, with reference to the latencies of OR in the three groups.

Peak V

Table 4.1

Mean and SD of Latencies of Peak V within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	6.47	0.33	6.38- 6.55	6	7.2
MA	57	6.51	0.30	6.42- 6.58	5.95	7.21
OA	57	8.03	0.43	7.91- 8.14	7.1	8.66
Total	171	7.00	0.81	6.87- 7.12	5.95	8.66



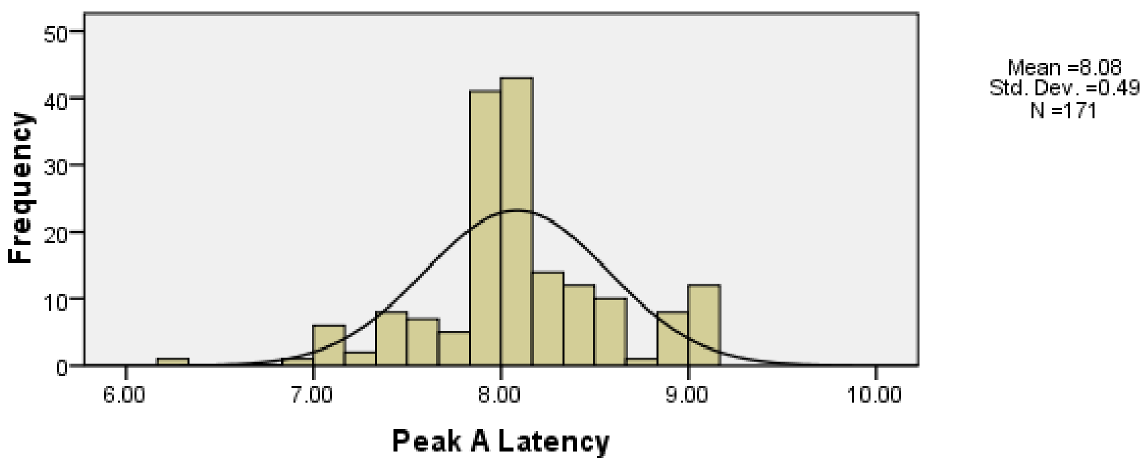
Graph 4.1: Distribution of data - Peak V

Peak A

Table 4.2

Mean and SD of latencies of Peak A within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	7.79	0.29	7.71- 7.87	7	8.1
MA	57	7.86	0.36	7.76- 7.95	6.33	8.3
OA	57	8.60	0.32	8.52- 8.69	8	9
Total	171	8.08	0.49	8.01- 8.16	6.33	9



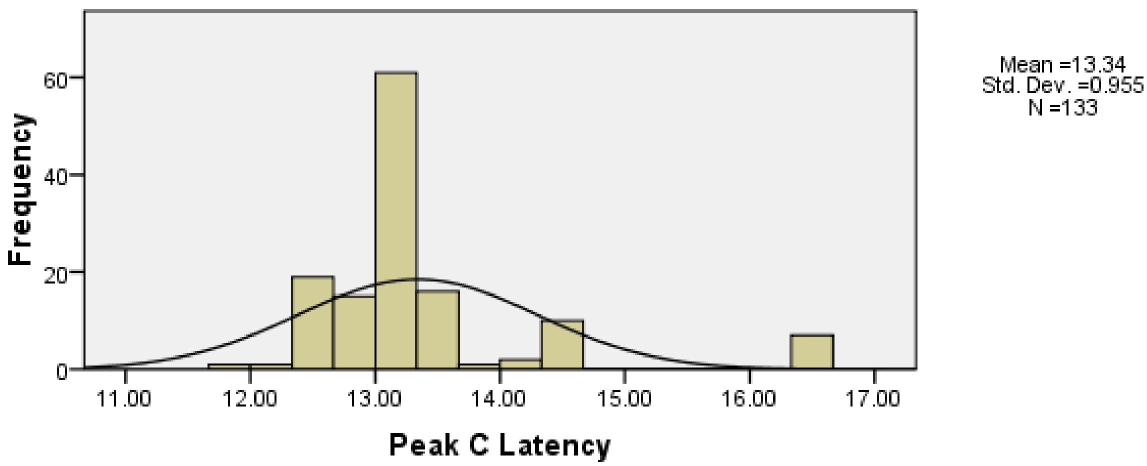
Graph 4.2: Distribution of data - Peak A

Peak C

Table 4.3

Mean and SD of Latencies of Peak C within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	13.16	0.18	13.12- 13.21	13	13.56
MA	57	13.84	0.38	12.7- 12.9	11.99	13.76
OA	19	15.32	1.06	14.8- 15.8	14.01	16.66
Total	133	14.34	0.95	13.17- 13.5	11.99	16.66



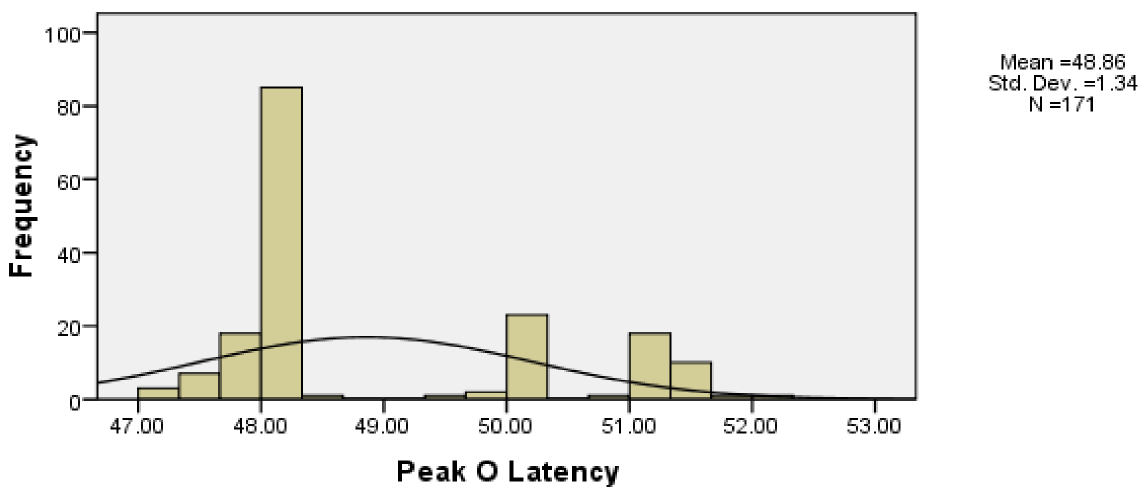
Graph 4.3: **Distribution of data - Peak C**

Peak O

Table 4.4

Mean and SD of Latencies of Peak O within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	48.02	0.09	48.00- 48.05	47.69	48.4
MA	57	48.88	0.23	47.82- 47.95	47.0	48.12
OA	57	50.66	0.65	50.48- 50.83	49.5	52.00
Total	171	49.86	1.34	13.17- 13.5	47.00	52.00



Graph 4.4: **Distribution of data - Peak O**

The series of Tables 4.1 to 4.4 and Graphs 4.1to 4.4, represent the Mean (SD) latencies in msec for the peak V in YA as 6.47msec (SD: 0.33), MA, 6.51 msec (SD: 0.30) and OA, 8.03msec (SD: 0.43). The latency for peak A in YA was 7.79msec (SD: 0.29), MA, 7.86msec (SD: 0.36) and OA, 8.60 msec (SD: 0.32) respectively. For peak C, the mean latency for the YA was 13.16 msec (SD: 0.18), MA, 13.84 msec (SD: 0.38) and OA, 15.32 msec (1.06).The mean latency for the peak O for the YA was 48.02 msec (SD: 0.09) and MA, 48.88msec (SD: 0.23). However, in OA, the peak O mean latency was found to be 50.66 msec (SD: 0.65). It is relevant to note that there was a significant difference in mean latencies for all the peaks with age increase. A notable difference was seen in the mean latencies for the peak V and O, while in peak A, which is the slope followed by the peak V, there was a gradual prolongation in latencies from YA to OA groups. The peak C latencies have shown a slightly different pattern in YA and MA groups with reduced or near absent peak C in majority of the OA groups.

4.1.2. Amplitudes of the OR- V A C and O

The results of amplitudes of OR- peaks V, A, C, and O in each age group are presented in Table.4.5.

Table. 4.5

Mean and SD of Amplitudes of OR in different groups

Peak	Age group*	Mean	Standard Deviation
V	YA	0.27	0.03
	MA	0.27	0.03
	OA	0.20	0.01
A	YA	-0.42	0.02
	MA	-0.42	0.02
	OA	-0.30	0.01
C	YA	-0.25	0.01
	MA	-0.25	0.01
	OA	-0.86	0.12
O	YA	-0.20	0.01
	MA	-0.20	0.01
	OA	-0.20	0.11

*n=57x3=171 *Age groups YA- Younger Adult, MA- Middle aged, OA- Older Adult.

From Table 4.5, it is evident that the Mean (SD) amplitudes in µv for the peak V were 0.27 µv (SD: 0.033), 0.27 µv (SD: 0.030) and 0.20 µv (SD: 0.009) for the YA, MA and OA groups respectively. The amplitudes for peak A were -0.42 µv (SD: 0.022), -0.42 µv (SD: 0.022) and -0.30 µv (SD: 0.014) for the groups YA,MA and OA respectively. For peak C, the mean amplitudes were, for the YA group:-0.25 µv (SD: 0.01), MA group,-0.25 µv (SD: 0.01) and for the OA group,-0.86 µv (0.11).The mean amplitude for peak O for the YA group was -0.20 µv (SD: 0.009); for the MA group, it was -0.20 µv (SD: 0.23) and for the OA group, -0.20 µv (SD: 0.11).Scrutiny of these results indicates that participants from MA and OA groups showed a variation in the amplitudes for the OR; however, a statistically significant reduction in amplitudes was noticed only in the OA groups. The changes in amplitudes were predominantly seen in peak C as compared to the changes observed in peaks A and O.

4.1.3. Latencies of the SR- D E and F

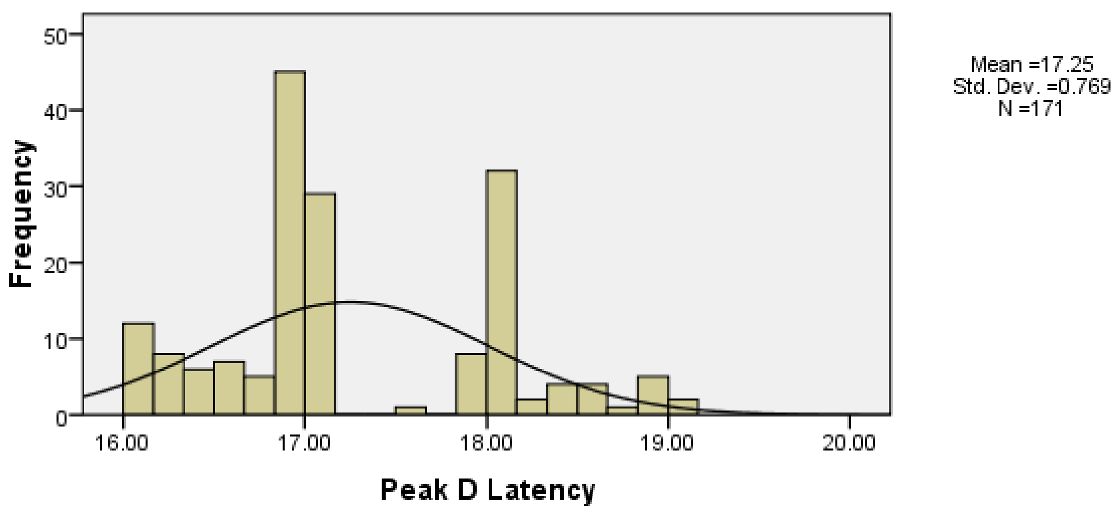
The mean latencies of the peaks D E and F for the three groups and depicted in Tables 4.6 to 4.8 and Graphs 4.5 to 4.7

Peak D

Table 4.6

Mean and SD of Latencies of Peak D within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	16.88	0.24	16.82- 16.95	16	17.1
MA	57	16.65	0.45	16.53- 16.77	16	18
OA	57	18.47	2.25	17.88- 19.07	17.66	35
Total	171	17.34	1.55	17.10- 17.57	16	35



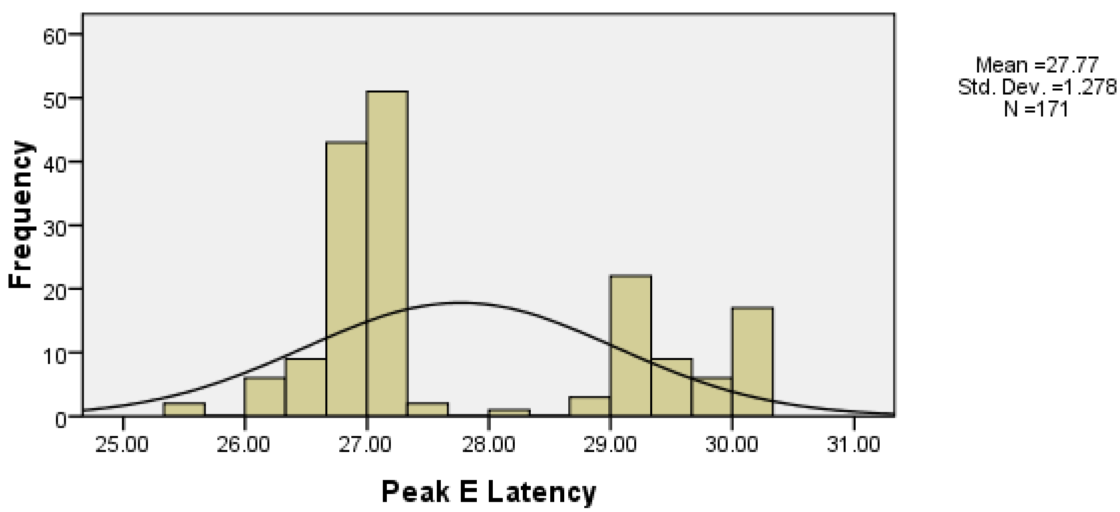
Graph 4.5: Distribution of data - Peak D

Peak E

Table 4.7

Mean and SD of latencies of Peak E within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	26.82	0.37	26.72- 26.92	25.44	28.0
MA	57	26.99	0.21	26.93- 27.04	26.29	27.51
OA	57	29.48	0.49	29.35- 29.61	17.66	30.26
Total	171	27.77	1.27	27.57- 27.99	25.44	35.26



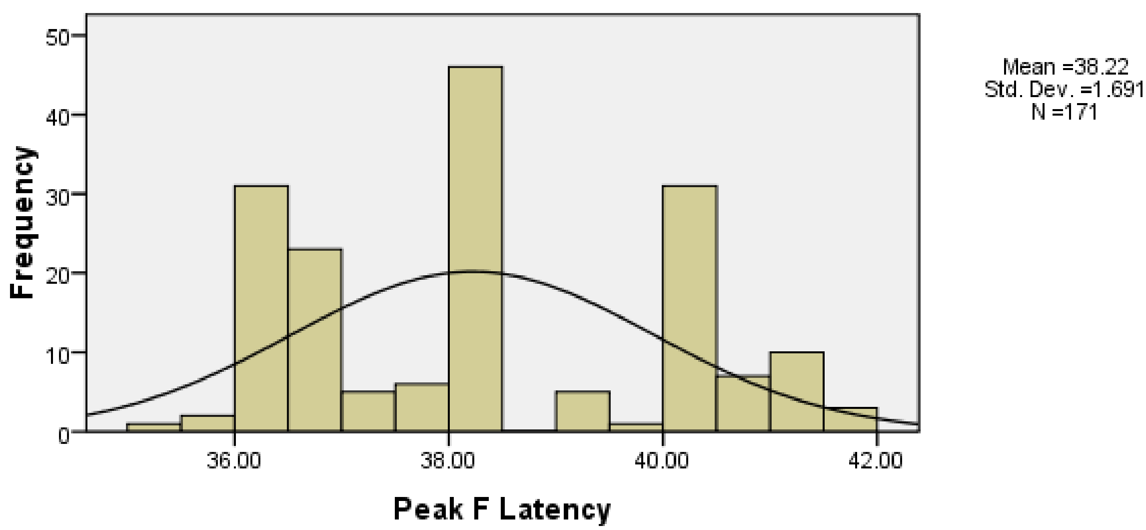
Graph 4.6: Distribution of data - Peak E

Peak F

Table 4.8

Mean and SD of latencies of Peak F within each group

	N	Mean	S.D	95% CI	Min	Max
YA	57	36.47	0.43	36.36- 36.59	35.66	37.88
MA	57	37.87	0.62	37.7- 38.03	35	38.36
OA	57	40.31	0.64	40.14- 40.48	39	41.66
Total	171	38.22	1.69	37.96- 38.47	35	41.66



Graph 4.7: Distribution of data - Peak F

From the series of Tables 4.6 to 4.8 and Graphs 4.5 to 4.7, it can be deciphered that the Mean (SD) latency in msec for the peak D in YA group was 16.88 msec (SD: 0.24): 16.65 msec (SD: 0.45) for the MA group while in OA group, 18.47 msec (SD: 0.25). The latency for peak E in YA group was 26.82msec (SD: 0.37); MA group, 26.99msec (SD: 0.21) and for OA group, 29.48 msec (SD: 0.49).For peak F, the mean latencies for the groups were 36.47 msec

(SD: 0.43) 37.87 msec (SD: 0.62) and 40.31msec (0.64) for YA, MA and OA groups respectively. The results of the SR indicate significant changes in the peak latencies with the increase in age. The changes were predominantly observed in the peak F of the FFR, wherein significant prolongation of the latencies for the OA group was evident. Interestingly, for the Peak D, the mean latencies showed a large variation in the SD, which endorses the variations seen in the recorded population. Additionally, the changes observed for the OA group were significant for the peaks E to F, contributing to the overall prolongation of the latencies in that group.

4.1.4. Amplitudes of the SR- D E and F

The amplitudes of the peaks D, E and F as obtained from the different age groups are shown in Table 4.9.

Table 4.9

Mean and SD of Amplitudes of SR within each group

Peak	Age group*	Mean	Standard Deviation
D	YA	-0.34	0.02
	MA	-0.34	0.02
	OA	-0.24	0.01
E	YA	-0.35	0.02
	MA	-0.35	0.02
	OA	-0.31	0.09
F	YA	-0.38	0.01
	MA	-0.38	0.01
	OA	-0.34	0.01

*n=57x3=171*Age groups YA- Younger Adult, MA- Middle aged, OA- Older Adult.

From Table 4.9, it is seen that the Mean (SD) amplitudes in µv for the peak D in YA group and MA were -0.34 µv (SD: 0.015), while in the OA group, -0.24 µv (SD: 0.011). The amplitudes for peak E in YA and MA groups were -0.35 µv (SD: 0.015) and for the OA group, - 0.31 µv (SD: 0.090). For peak F, the mean amplitudes for the YA and MA groups were -0.38 µv (SD: 0.014) and for the OA group, it was -0.34 µv (0.014).Interestingly, it is to be noted that the amplitude difference among the YA and MA groups was minimal. However, in OA group, the amplitude mean differences were lower as compared to the other two groups. It is interesting to note the significant effect on the latency measures in spite of the shift in FFR amplitude being minimal. This could be attributed in the neural breakdown in the processing of the speech sounds.

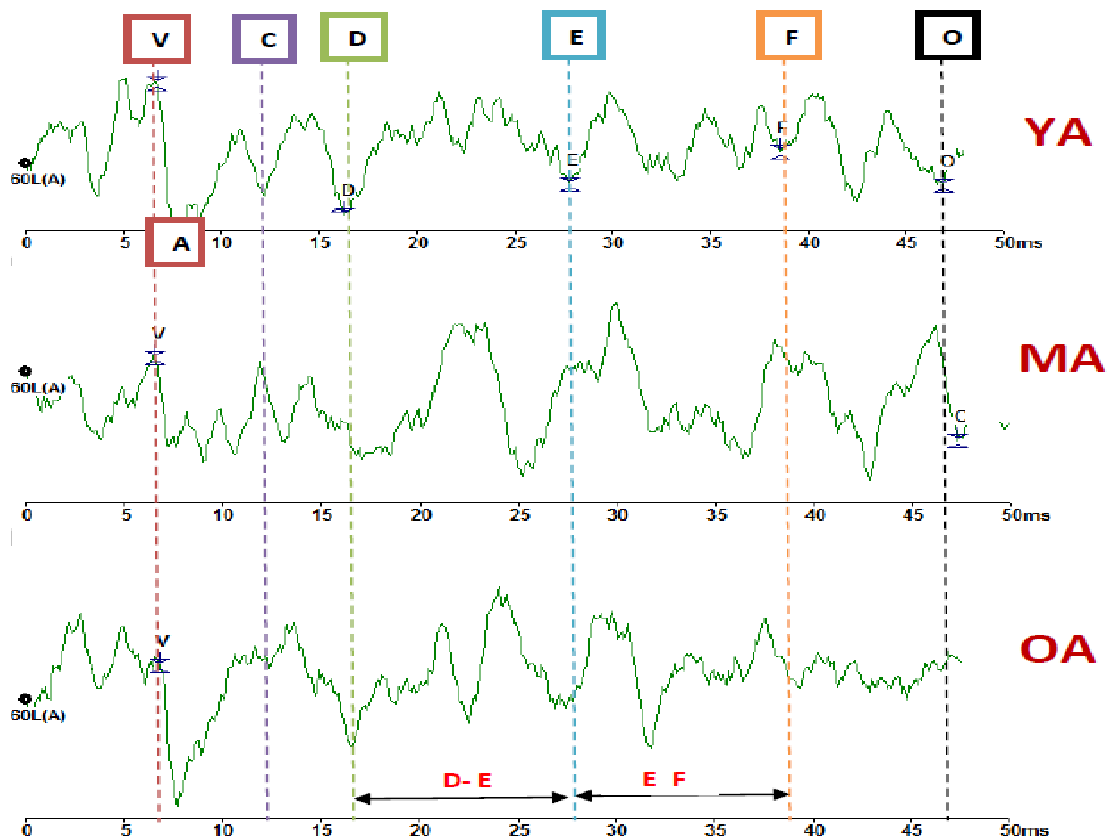


Figure 4.1. SEABR responses- for the YA, MA and OA

4.2 Comparison of SEABR in YA, MA and OA

The SEABR responses for the three groups in terms of mean latencies and amplitudes of the OR and SR *(Figure: 4.1)* for the syllable /da/ were compared using Analysis of Variance (ANOVA). Further, multiple comparisons were done using Post-Hoc test (Bonferroni).

4.2.1. Comparison of mean latencies of the OR

a. Peak V

Comparison of mean latencies of the OR for SEABR/da/ was done for the peak V separately. The ANOVA results and the post hoc measures using Bonferroni are given in Tables - 4.10, 4.11 and Graph 8.

ANOVA results

Table 4.10

Peak V versus the age groups

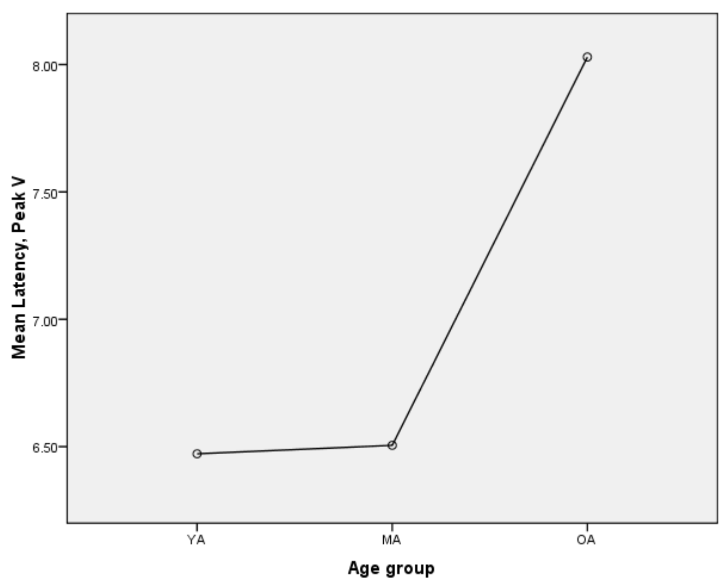
	Sum of squares	df	Mean Square	F	P value
Between Groups	90.23	2	45.11	356.4	<0.001
Within Groups	21.26	168	0.12		
Total	111.49	170			

Multiple Comparisons- Bonferroni

Table 4.11

Multiple Comparisons of peak V versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	-0.03	1.000
	OA	-1.56	<0.001
MA	YA	0.03	1.000
	OA	-1.52	<0.001
OA	YA	1.56	<0.001
	MA	1.52	<0.001



Graph 4.8: Comparison of mean latency of peak V versus the age groups

For the peak V, there was a statistically significant difference between groups as determined by one-way ANOVA (F (2,168) = 356.4, p <0.001). A Bonferroni post-hoc test revealed that the value of peak V was significantly higher in the OA group (8.03 ± 0.43, *p*<0.001) than YA group (6.47 ± 0.33, *p* <0.001) and MA group (6.51 ± 0.30, *p* <0.001).There were no statistically significant difference between the YA group and MA group (*p* = 1.00).

b. Peak A

Comparison of mean latencies of the OR for SEABR/da/ was also done for the peak A separately. Results of ANOVA results and post hoc measures Bonferroni are provided in Tables-4.12, 4.13 and Graph 4.9.

ANOVA results

Table 4.12

Peak A versus the age groups

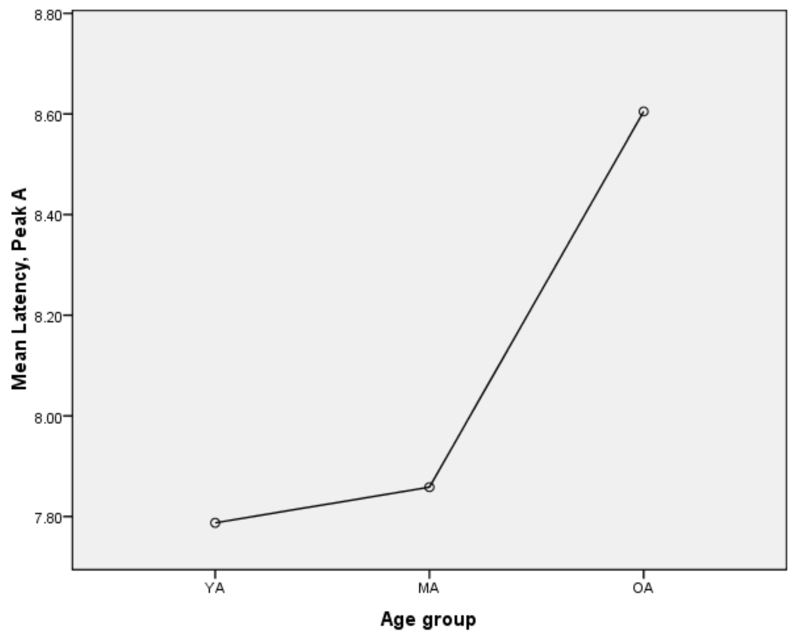
	Sum of squares	df	Mean Square	F	P value
Between Groups	23.37	2	11.69	112.2	<0.001
Within Groups	17.50	168	.104		
Total	40.88	170			

Multiple Comparisons- Bonferroni

Table 4.13

Multiple Comparisons of peak A versus the age groups

`	Group	Mean Difference	*P*value
YA	MA	-0.07	0.73
	OA	-0.82	<0.001
MA	YA	0.07	0.73
	OA	-0.75	<0.001
OA	YA	0.82	<0.001
	MA	0.75	<0.001



Graph 4.9: Comparison of mean latency of peak A versus the age groups

For the peak A, there was a statistically significant difference between groups as determined by one-way ANOVA ($F(2,168) = 112.2$, $p < 0.001$). A Bonferroni post-hoc test revealed the value of peak A to be significantly higher in the OA group (8.60 ± 0.32, $p<0.001$) than the YA group (7.79 ± 0.29, $p < 0.001$) and MA group (7.86 ± 0.36, $p < 0.001$).There were no statistically significant differences between the YA group and MA group ($p = 0.73$).

c. Peak C

Comparison of mean latencies of the onset responses for SEABR/da/ was also done separately for the peak C. ANOVA results and the post hoc measures done using Bonferroni are furnished in Tables-4.14, 4.15 and Graph 4.10.

ANOVA results

Table 4.14

Peak C versus the age groups

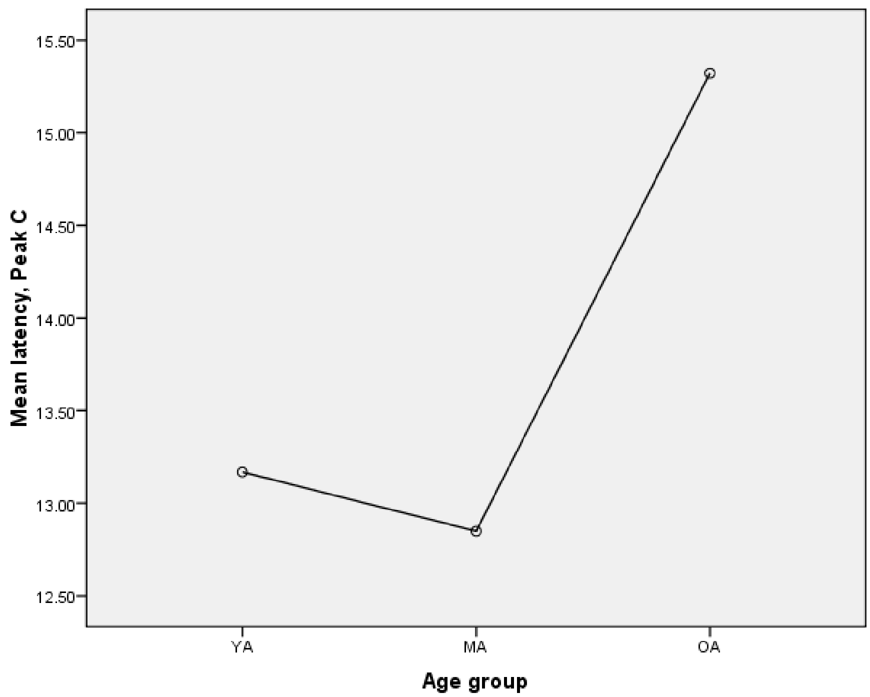
	Sum of squares	df	Mean Square	F	*p* value
Between Groups	90.02	2	45.01	193.46	<0.001
Within Groups	30.24	130	0.233		
Total	120.27	132			

Multiple Comparisons- Bonferroni

Table 4.15

Multiple Comparisons of peak C versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	0.32	0.32
	OA	-2.15	-2.15
MA	YA	-0.31	-0.31
	OA	-2.47	-2.47
OA	YA	2.15	2.15
	MA	2.47	2.47



Graph 4.10: Comparison of mean latency of peak C versus the age groups

A statistically significant difference was noted between groups as determined by one-way ANOVA ($F(2,130) = 193.4$, $p < 0.001$).A Bonferroni post-hoc test revealed the value of peak C to be significantly higher in the OA group (15.32 ± 1.06) than the YA group (13.16 ± 0.18, $p < 0.001$) and MA group (12.84 ± 0.38, $p < 0.001$). Peak C was significantly lower in the MA group (12.84 ± 0.38) than the YA (13.16 ± 0.18), $p = 0.002$.

d. Peak O

Comparison of mean latencies of the onset responses for SEABR/da/ was done for the peak O separately. The ANOVA results and the post hoc measures done using Bonferroni are given in Table-4.16, 4.17 and Graph 4.11.

ANOVA results

Table 4.16

Peak O versus the age groups

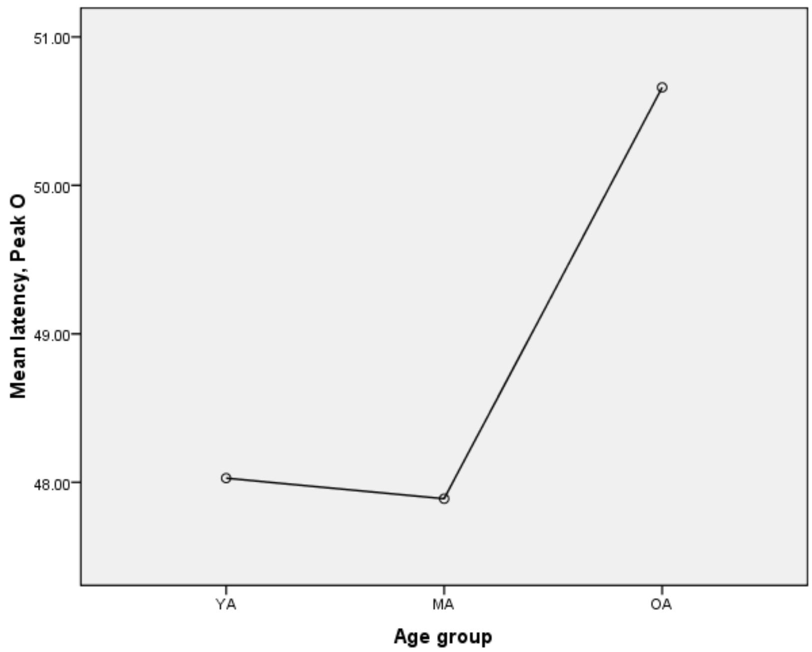
	Sum of squares	df	Mean Square	F	*p* value
Between Groups	277.83	2	138.91	852.9	<0.001
Within Groups	27.36	168	0.163		
Total	305.19	170			

Multiple Comparisons- Bonferroni

Table 4.17

Multiple Comparisons of peak O versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	0.13	0.207
	OA	-2.63	<0.001
MA	YA	-0.13	0.207
	OA	-2.77	<0.001
OA	YA	2.63	<0.001
	MA	2.77	<0.001



Graph 4.11: Comparison of mean latency of peak O versus the age groups

For the offset responses, peak O revealed a statistically significant difference between groups as determined by one-way ANOVA ($F(2,168) = 852.9$, $p < 0.001$). A Bonferroni post-hoc test revealed that the value of peak O was significantly higher in the OA group (50.66 ± 0.65) than the YA group (48.02 ± 0.099, $p < 0.001$) and MA group (47.88 ± 0.23, $p < 0.001$).There were no statistically significant differences between the YA group and MA group ($p = 0.207$).

4.2.2. Comparison of mean latencies of the SR

a. Peak D

Comparison of mean latencies of the SR for SEABR/da/ was done for the peak D separately. ANOVA results and the post hoc measures done using Bonferroni are given in Tables-4.18, 4.19 and Graph.4 12.

ANOVA Results

Table 4.18

Peak D versus the age groups

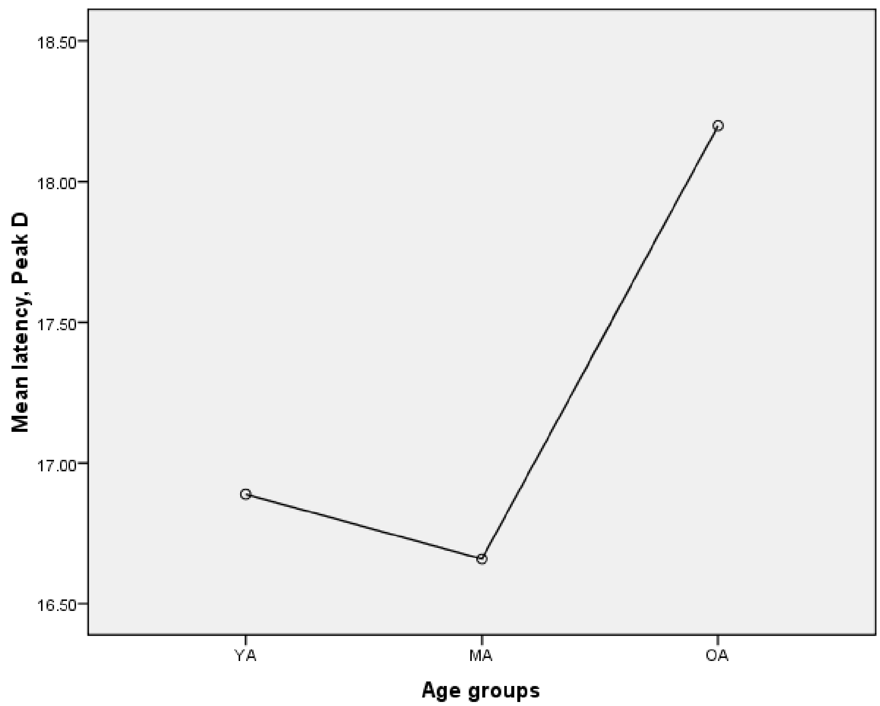
	Sum of squares	df	Mean Square	F	P value
Between Groups	111.97	2	55.9	31.45	<0.001
Within Groups	299.02	168	1.78		
Total	410.99	170			

Multiple Comparisons- Bonferroni

Table 4.19

Multiple Comparisons of peak D versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	0.22	1.000
	OA	-1.59	<0.001
MA	YA	-0.22	1.000
	OA	-1.81	<0.001
OA	YA	1.59	<0.001
	MA	1.81	<0.001



Graph 4.12: Comparison of mean latency of peak D versus the age groups

For the peak D, there was a statistically significant difference between groups as determined by one-way ANOVA (F (2,168) = 31.45, p <0.001). A Bonferroni post-hoc test revealed peak D to be significantly higher in the OA group (18.47 ± 2.25, p<0.001) than the YA group (16.88 ± 0.24, p <0.001) and MA group (16.65±0.45, p <0.001). There were no statistically significant differences between the YA group and MA group (p = 1.00).

b. Peak E

Comparison of mean latencies of SR for SEABR/da/ was done for the peak E separately. ANOVA results and the post hoc measures had done using Bonferroni are as shown in Tables-4.20, 4.21 and Graph 4.13.

ANOVA results

Table 4.20

Peak E versus the age groups

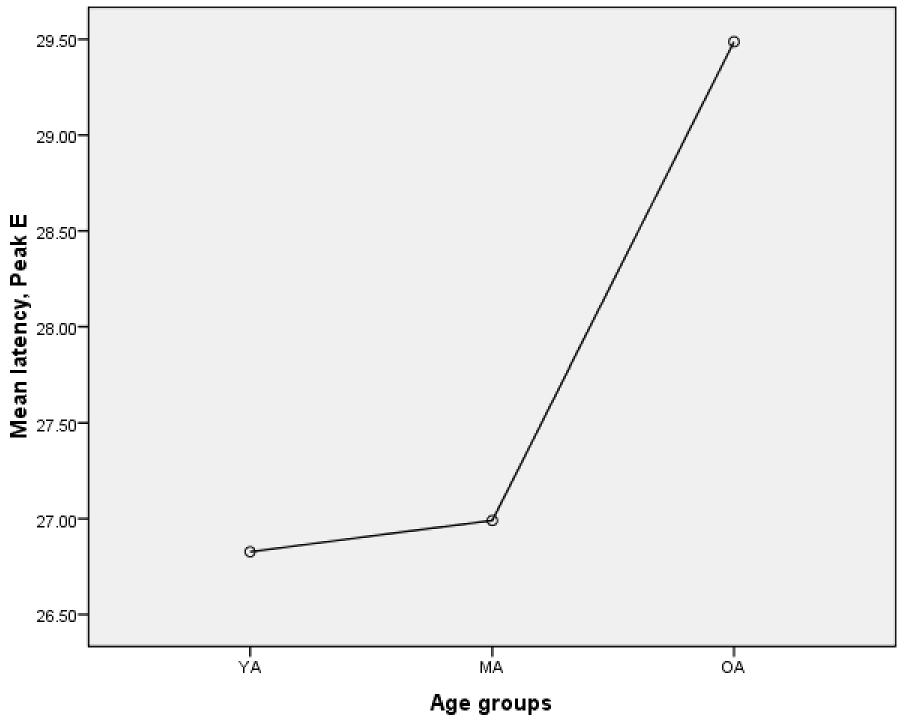
	Sum of squares	df	Mean Square	F	*p* value
Between Groups	253.34	2	126.6	880.17	<0.001
Within Groups	24.18	168	0.144		
Total	277.52	170			

Multiple Comparisons- Bonferroni

Table 4.21

Multiple Comparisons of peak E versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	-0.16	0.068
	OA	-2.56	<0.001
MA	YA	0.16	0.068
	OA	-2.49	<0.001
OA	YA	2.65	<0.001
	MA	2.49	<0.001



Graph 4.13: Comparison of mean latency of peak E versus the age groups

For the Peak E, there was a statistically significant difference between groups as determined by one-way ANOVA (F (2,168) = 880.02, p <0.001). A Bonferroni post-hoc test revealed that the value of peak E was significantly higher in the OA group (29.48 ± 0.49, p<0.001) than the YA group (26.82 ± 0.37, p <0.001) and MA group (26.99±0.21, p <0.001).There were no statistically significant differences between the YA group and MA group (p = 0.068).

c. Peak F

Comparison of mean latencies of the SR for SEABR /da/ was done for the peak F separately. ANOVA results and the post hoc measures done using Bonferroni are provided in Tables-4.22,4.23 and Graph.4.14.

ANOVA results

Table 4.22

Peak F versus the age groups

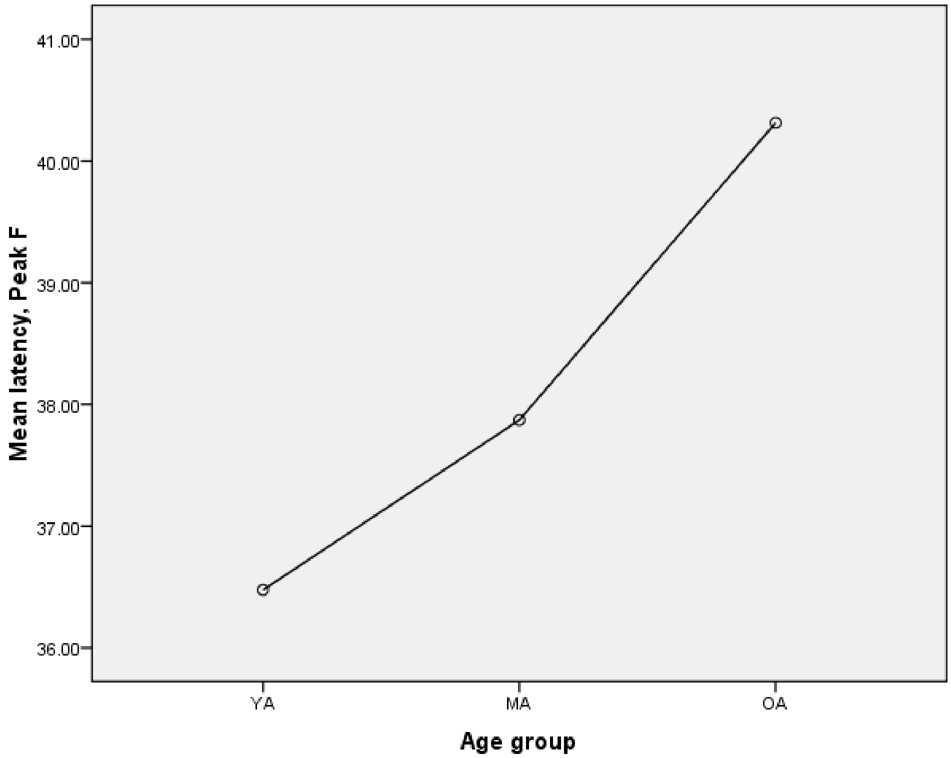
	Sum of squares	df	Mean Square	F	P value
Between Groups	430.35	2	215.17	649.1	<0.001
Within Groups	55.69	168	0.33		
Total	410.99	170			

Multiple Comparisons- Bonferroni

Table 4.23

Multiple Comparisons of peak F versus the age groups

Group	Group	Mean Difference	*p* value
YA	MA	-1.39	<0.001
	OA	-3.83	<0.001
MA	YA	1.39	<0.001
	OA	-2.44	<0.001
OA	YA	3.83	<0.001
	MA	2.44	<0.001



Graph 4.14: Comparison of mean latency of peak F versus the age groups

There was a statistically significant difference between groups as determined by one-way ANOVA (F (2,168) = 649.1, p <0.001) for this peak. A Bonferroni post-hoc test revealed that the value of peak V was statistically significantly higher in the OA group (40.31 ± 0.64, p<0.001) than the YA group (36.47 ± 0.43, p <0.001) and MA group (37.87±0.64, p <0.001).The MA group (37.87±0.64, p<0.001) had significantly higher Peak F values than the YA group (36.47 ± 0.43, p <0.001).

OR in YA, MA and OA

The OR in SEABR was defined as the responses obtained for the burst portion of the consonant vowel stimulus /da/. It involves four distinct peaks and offers an array of information on how the signals such as complex speech sounds are processed in the brain stem and expected to be encoded at milliseconds duration. It constitutes the peak 'V' , followed by the negative trough ‘A’, then the stimulus transition from consonant to vowel ‘C’ and finally the offset response or the cessation of the stimulus ‘O’.

The function of the neurons in the auditory nerve and in the brain stem level is integral for the transition of the acoustical signal to the higher order auditory structures. The burst portion of the syllable /da/ in all the three age groups provided useful information on how the transition of aging affects the brain stem signal processing and its decline in the temporal processing in humans. The study results are consistent with the growing literature on aging and temporal processing *(Clinard, Tremblay & Krishnan,2010, Anderson et al 2013, Grose Mamo, Buss, & Hall,2015,).* The lack of prominent effect of latency and amplitude shifts in the fourth or the fifth decade of life is an interesting finding from the data when analyzed with post hoc measures.

In the present study, it was hypothesized that the neural encoding of speech sounds would deteriorate with advances in age. The results from the data support this hypothesis, at least in the context of latency and amplitude measures, the two important components in peak picking in SEABR which were affected in OA group as compared to the YA and MA groups. Statistically significant differences were observed for the OA group as compared to the YA and MA groups. The responses for the YA and MA groups remained the same with statistically no significant differences in latency and amplitude of the OR. Similar findings have been reported in the study by *Vander Werff and Burns (2011)* while comparing the SEABR and Click ABR measures in YA and MA. They reported that the onset portions of the syllable /da/ possessed high energy and required the synchronous firing of all burst neurons to segment the signal level at the brainstem level and eventually giving rise to a peak at 7 ms, similar to that of the click evoked ABR. Consistent with the current findings, they reported that there is a significant prolongation of OR, especially of the peak V seen in OA.

The OR were expected to evoke a coordinated firing of various neurons in the auditory brain stem structures, especially with the complex sounds such as syllable /da/ challenging the auditory system to process the signals. The decline in the amplitude and increase in the latency of wave ‘V’, wave ‘A’ and disappearance of wave ‘C’ in certain OA group indicates significant challenges faced by certain weak neurons in the brainstem level and being responsible in the neural breakdown as depicted in the SEABR. Further, the efficiency of onset / burst neurons responsible for sending the signals within a micro second is compromised as a result of neural degeneration occurring in the human auditory system due to aging. The OR of SEABR particularly reflects the synchronous neural firing of many brain stem cells at the level of cochlear nucleus and inferior colliculus *(Akhoun et al, 2008a)*. It can hence be postulated that these neurons are likely to be affected by the advances in age and attribute to the prolonged latencies of OR. The time required for the neural conduction of such fast and time varying sounds produces many cues for the listener to understand the context as well as the features of the sound. The reduction in the pace or speed at which the acoustic information is processed through the brain stem substantiates the known theory of temporal processing deficit in aging auditory system *(Gordon –Salant& Friedman 2011,Anderson et al 2013,Grose et al 2015)*, that impinges on the evidences from objective measures such as SEABR.

Much of the studies reported in the literature on SEABR have focused mainly on the pediatric population and have reported that the functional decline in the encoding of OR leads to the decline in the auditory speech perception in children, especially in the learning disabled group *(Warrier, Johnson, Hayes, Nicol, & Kraus,2004, Wible et al 2005,Banai& Kraus 2006, Strait Hornickel&Kraus ,2011).* The results of the preliminary study of *Ayas, Rajashekhar &Yaseen (2015)* indicate that SEABR would be present in infants and will show functional changes with age increase. Consistent with these findings, it can be stated that the auditory system has its developmental course from infancy to adolescence with the plateau of the responses in the fourth to the fifth decade of life. Further, the current data indicated that the OA groups showed a marked decline in the OR for the peak V followed by peak C and peak O. The study by *Clinard et al 2010* on the affect of SEABR on advancing age reflects similar findings for the OR.

The results of the current study are in general agreement with the study reported by *Clinard et al,* in *(2010)* and *Clinard & Tremblay (*2013) in terms of the reduced amplitude and delayed latencies seen for the OR in OA. These changes in the responses were consistent with the reduction in the synchronous firing of neurons to the transient changes in speech and the reduction in neural encoding of the transition and offset responses of the speech stimulus in the aging auditory system. *Johnson et al (2007)* also reported on similar lines in their study conducted in children with learning problems.

Though a drastic decline in the amplitude of offset responses for the peak O was not noted, relatively longer latencies were recorded for the peak. There was a statistically significant lengthening of the latencies in the OA group as compared to the YA group. In agreement with the findings of *Vander-Werff and Burns (2011),* the prolonged latency for wave O could be attributed to the reduced synchrony of certain section of neuron fibers at the

brain stem level. Studies have indicated that the offset response for various long duration stimuli represents reduced firing rate at the end of the stimulus duration. It was further suggested that these offset responses are generated from a particular offset type of neurons sensitive to duration and detrimental in prolonged latencies in the OA groups *(Van Campen, Hall, & Grantham,1997, Faure Fremouw, Casseday, & Covey,2003, Johonson et al, 2007).*
It has been reported that there are specific neurons which are needed for the offset response of the stimulus or stimulus duration in the inferior colliculus *(Covey at al 1996).* Studies done on pediatric population have reported that the reduction in amplitude and prolongation of latencies affect the segregation of speech sounds from that of the background noise *(Johnson et al 2007, Skoe et al 2015)*.This information could be helpful in understanding the most common complaints reported by the older adults that "I can hear you but cannot understand the speech clearly."The temporal processing abilities are critical in segregating the speech and understanding the content of the signal. Such information is considerably important and not provided by non-speech ABR stimuli such as clicks or tone burst ABR and thus emphasizes SEBAR as an important measure in unravelling the complex processing in humans.

The reduced amplitude and prolonged latency measures are consistent with the reduced neural firing of the transient portion of the signal. This may result in the reduction in encoding rapidly changing acoustic cues such as syllable transitions, evident in most of the OA adults with reduced or no discernible peaks. This information is unfavourable in following speech in the presence of background noise or in reverberant conditions (*Song et al 2011;Kraus & Anderson, 2015,).* Evidence from the findings of this study enables the postulation that the breakdown in the neural encoding of transient responses leads to the decoupling of syllable transitions of the speech signal. For instance, the consonant- vowel segments were detached and resulted in staggered representation of the ongoing signal in the higher order auditory centers in the brain.

Although it is understood that the OA adults are prone for temporal processing defects, much of the concepts were postulated from the behavioral and psycho physical measures. Recent interest in the objective measures to quantify the findings of these responses have led to the proliferation of SEABR studies in a specific group of children who possess hearing difficulties *(Chandrashekharan et al 2009, Anderson,Skoe, Chandrasekaran, & Kraus, 2010,Hornickel& Kraus,2011,Strait et al 2011)* and also in a section of aging group *(Anderson et al 2011,Anderson et al 2013, Kraus & Anderson 2013,Kraus & Anderson, 2014).* Thus, the objectivity of the SEABR encourages the users to extract crucial information from SEABR, like in the present study. The profound information that could be extracted from the data revealed that the OR is critical in understanding the speech signal. In addition, ability of the auditory system to encode such rapid changes in the signal would provide cues to the listener on the various aspects of the signal, be it in quiet or in noisy conditions *(Neha et al, 2012).* This emphasizes that the auditory system requires a synchronous firing of various types of neurons to process the signal to higher order centers when the auditory system is exposed to more competent and complex environment such as cafeterias , restaurants , hotels , while travelling etc. The findings on the OR of this study further highlight the importance of hearing aid selection and rehabilitation in elderly with hearing loss. It is presumed that the objective fine tuning of the rapidly time varying signals through hearing aids would eventually help these individuals in understanding speech clearly.

SR - FFR in YA, MA and OA

SR in SEABR was defined as the phase locked response to the frequency component of the voiced portion of the syllable /da / and also termed as Frequency Following Response (FFR).The analysis of the obtained data revealed statistically significant changes in latency and amplitude in the OA group participants than in the other two groups. Individual peak analysis also sheds light on the possible causes for the breakdown in signal processing in individuals with advanced age. The SR portions are thought to be generated from the brainstem structures in response to an acoustic stimulus in a phase locked manner, which mimics the phase of the signal itself. The overall shift in the FFR responses for OA group in the current study could possibly indicate that the reduced phase locking responses indeed prolong the response latencies for the vowel portion of the stimulus.

Neurophysiologically, these changes in the latencies were attributed to the overall neural firing rate and the ability of different fiber neurons to actually disrupt the signal processing in the gateway structure of the auditory system. The components of FFR which were high in energy could be affected when the OA group was exposed to challenging situations. This requires them to have synchronous firing of all neurons to extract the acoustic portion of the speech signal for the better representation at the brainstem level. Even though the vowels have higher energy in the signal compared to the onset portion of the signal, in complex environment, the individuals do pose difficulties in processing the acoustic information of the signal, such as speaker identification, which is integral for the overall communication. Thus, reduced responses could lead to altered auditory images in the brain stem level, which could eventually affect the cortical representation of speech sounds. Studies done on various background noises reflect similar findings in OA groups *(Neha et al, 2012,* *Anderson & Kraus 2013).* However, during the transition from the MA to the OA group, the effect was gradual on the measures of FFR. This could, in turn lead to further research questions on at what age does the FFR declines. From the results of the current study, it could be stated that a specific age is difficult to pronounce in cases of FFR responses; however, it was observed that after 54 years and above, the changes could be seen in FFR responses.

Consistent with the behavioral findings on temporal processing decline in OA, the current study further adds dimension to the effect of aging on the vowel perception in competing environment. It is believed that during the fifth decade of life, human auditory system and associated neurons undergo various vascular and metabolic changes, which result in the variations of the FFR responses, though expected to be high in energy. *Neha et al ,2012,* reported similar findings in SEABR measures with the use of SEABR recorded in quiet and noise with the syllable/da/. In their study, speech sounds in three different conditions were presented and the amplitude and latency measures in SEABR were affected as the signal to noise ratio was zero or less when the auditory system required segregation of speech sounds in the presence of noise. Similar findings are found in the literature on adults and children *(Anderson et al 2013).*

Though there are reports in the literature on the various sources for the generation of OR and SR for SEABR, this study considered the current findings as a whole mechanism generation in the auditory brain stem. This aspect warrants further research to endorse and substantiate the reports in the literature. Findings from the current study, however partially support the literature on the mechanism by which sounds are encoded and the effect of age on the complex sound processing on the gateway structure in the brain stem *(Kraus & Nicol,* *2005, Banai et al ,2005; Skoe& Kraus,2009)*. Further, it would be prudent to focus on the advanced use of SEABR in unravelling the ongoing mystery in the temporal processing decline in human population as future endeavours.

4.3 SEABR in first time hearing aid (HA) users

The demographic details of the first time hearing aid users (n=29) are given below in Table.

Table 4.24

Demographic details of the first time HA users

Sl No	Age	Gender	HA- Ear	Duration of hearing loss/years	PTA (dBHL)
1	56	Male	Right	4	48
2	58	Male	Left	2	45
3	58	Male	Left	1	55
4	61	Male	Left	.8	55
5	56	Female	Right	5	45
6	55	Male	Right	.9	45
7	55	Male	Right	6	45
8	56	Female	Right	1	50
9	59	Male	Left	1	52
10	62	Male	Left	2	50
11	66	Male	Right	2	55
12	64	Female	Right	.6	55
13	63	Male	Right	4	60
14	59	Male	Right	5	45
15	59	Female	Right	9	51
16	58	Female	Left	1	51
17	54	Female	Left	2	52
18	61	Male	Right	10	50
19	59	Male	Right	2	55
20	59	Male	Right	1	55
21	64	Male	Left	.9	45
22	55	Female	Right	3	50
23	57	Male	Left	4	55
24	55	Male	Left	2	55
25	59	Female	Right	1	55
26	71	Male	Right	1	45
27	68	Male	Right	5	50
28	61	Female	Right	2	52
29	57	Male	Right	9	52

4.3.1 Mean latency of OR in first time HA users

The mean latency for the peaks V, A, C and O for the first time HA users is depicted in Table - 4.25 and Figure .4.2

Table 4.25

Mean latencies of OR in first time hearing aid users

Peak	N	Mean	Standard Deviation
Peak V	29	9.51	0.50
Peak A	29	11.94	0.30
Peak C	0	-	-
Peak O	29	51.17	0.29

From the Table 4.25, it is evident that the Mean (SD) latency in msec for the peak V in first time HA users group was 9.51msec (SD: 0.50).The latency for peak A in first time HA users group was 11.94 msec (SD: 0.30). For peak C, no values could be obtained within the first time HA users group as depicted in the waveform. The mean latency for the peak O for the first time HA users group was 51.17 msec (SD: 0.29.) It was noticed that with the introduction of amplification to the moderate hearing loss participants, there was an improvement in mean latencies for all the peaks excepting for peak C. A notable observation is an acceptable margin of the aided peak A latency in the first time HA users, in spite of latency prolongation observed in the slope followed by the peak V.

4.3.2. Mean latency of SR in first time HA users

The mean latency for the peaks D,E and F for the first time HA users are given in Table-4.26.

Table 4.26

Mean latencies of SR in first time hearing aid users

Peak	N	Mean	Standard Deviation
Peak D	29	19.34	0.33
Peak E	29	30.60	0.45
Peak F	29	39.56	0.49

From the Table 4.26, it is seen that the Mean (SD) latency in msec for the peak D in first time HA users group was 19.34 msec (SD: 0.33).The latency for peak E in first time HA users group was 30.60 msec (SD: 0.45). The mean latency for the peak F for the first time HA users group was 39.56 msec (SD: 0.49).The results are encouraging in hearing aid users in whom the mean latencies followed a traditional variation in FFR latencies and being within the acceptable range.

4.3.3. Mean Amplitude of OR in first time HA users

The mean amplitudes of the peaks V, A C and O obtained from the first time HA users are presented in Table 4.27.

Table 4.27

Mean amplitudes of OR in first time hearing aid users

Peak	N	Mean	Standard Deviation
Peak V	29	0.23	0.036
Peak A	29	-0.29	0.017
Peak C	0	-	-
Peak O	29	-0.21	0.004

From the Table 4.27, it is seen that the Mean (SD) amplitude in μv for the peak V in first time first time HA users group was 0.23 μv (SD: 0.036), while for peak A, it was -0.29 μv (SD: 0.017). The amplitude for peak C could not be recorded in majority of the participants and hence assigned with a value of 0 and not considered for analysis. For the peak O, the mean amplitude was 0.21 μv (SD: 0.004).

4.3.4. Mean Amplitude of SR in first time HA users

The mean amplitudes for the peaks D,E and F obtained from the first time HA users are presented in Table 4.28.

Table 4.28

Mean amplitudes of SR in first time HA users

Peak	N	Mean	Standard Deviation
Peak D	29	-0.24	0.006
Peak E	29	-0.23	0.008
Peak F	29	-0.24	0.007

From the Table 4.28, it is observed that the Mean (SD) amplitude in µv for the peak D in first time HA users group was - 0.24 µv (SD: 0.006), while it was - 0.23 µv (SD: 0.008) for peak E. The amplitude for peak F for the first time HA users group was -0.24 µv (SD: 0.007).

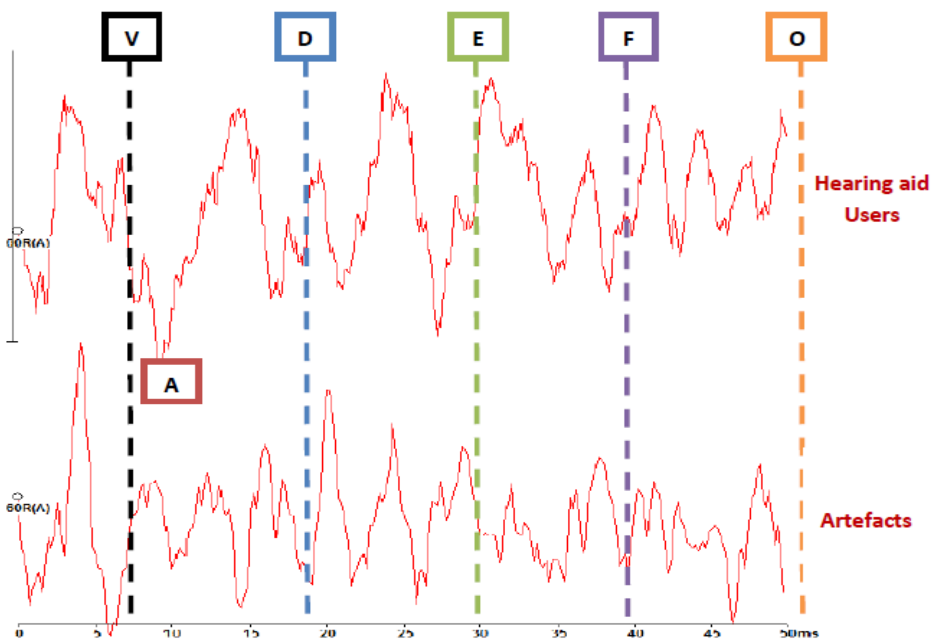


Figure: 4.2. SEABR responses-for the First time hearing aid users (top) and artefacts recorded with the hearing aids (Bottom)

The mean latencies of the first time HA users group and the OA group were compared (Table 4.29) using independent sample t test, to see if there was any equality of variance between them, though they did not share major characteristics in common other than being from similar age range.

Table 4.29

Comparison of SEABR in first time HA users versus OA group

	Levene's Test for Equality of variances		**t test for equality of means**		
	F	**p value**	**T**	**df**	**p value**
Peak V	2.445	.122	14.42	84	<0.001
Peak A	4.205	.043	47.04	84	<0.001
Peak O	59.83	.000	4.99	83.3	<0.001
Peak D	.452	.503	14.46	84	<0.001
Peak E	.777	.381	10.23	84	<0.001
Peak F	1.88	.173	5.46	84	<0.001

The purpose of this particular comparison was to see if the amplified signals in the first time HA users group were approximating the normal latency values of the OA group. The values of SEABR peak in first time HA users group and OA groups were compared. Independent 't' test showed significant differences for all the peaks in both the groups (*p value <0.001*). Though the groups did not show any commonality in the latency measures, closer scrutiny of the waveforms reflected the aided latencies reaching relatively closer values of the OA group. Considering the clinical utility of this research, the use of SEABR in quantifying the effectiveness of hearing aid fitting in OA with moderate sensorineural hearing loss was debated. In spite of the challenges underlying the utility of SEABR as a measure of the outcome of amplification devices for the hearing impaired, this study has shed light on its gross utility. Only advanced studies could provide definite and indepth answers on its utility.

Similar SEABR waveforms were anticipated in both the groups on the premise that providing amplification to hearing impaired followed the general rule of thumb- “amplify the impaired auditory system and attain hearing at a near normal speech spectrum” *(Hecox,1983,Beauchaine, Gorga, Reiland, & Larson, 1986,Billings, Tremblay, Souza, & Binns, 2007, Billings, Tremblay & Miller 2011).* It was interesting to find similarity of certain parameters of SEABR in first time HA user group with OA group. The results of this study indicate the possibility of using SEABR for recording the hearing aid amplified responses. Peak ‘C’ was absent in all the participants, which is important for the stimulus transition from consonant to vowel .This could reflect on the technological and circuitry based changes to be considered by the hearing aid manufacturers in their research and development endeavours of enhancing the benefits of amplification. Interestingly, the FFR responses were recorded with little variation in the latencies and the amplitude.

It is well documented in the literature that with increased intensity levels, amplitudes increase and latencies decrease in normal-hearing adults *(Gorga, Beauchaine, & Reiland, 1987; Adler & Adler, 1989, 1991)*. This logic could be applied to the outcome of amplification by hearing aids resulting in similar morphological changes as anticipated for SEABR in normal hearing. The optimal benefits of amplification complimented by effective rehabilitation depend on the auditory system’s ability to represent and integrate frequency and timing information contained in the speech signal *(Tremblay ,et al 2003, Tremblay ,et al 2004, & Tremblay et al, 2007, Billings, et al, 2011).*Given that speech perception depends on the neural detection of spectral and temporal cues, usage of SEABR will enable greater focus on the speech perception abilities in this population.

There is evidence to suggest that with the introduction of amplification via a hearing instrument, the auditory system is able to adapt to the new acoustic information provided *(Philibert Collet, Vesson, & Veuillet, 2005; Munro, Pisareva, Parker, & Purdy, 2007).* With the hearing aid in place, there is a systematic change in auditory performance that is linked to a change in the acoustic information available to the listener (*Munro et al.2007).* Hence, by the use of SEABR in a controlled manner, quantifiable information from the hearing aid users could be measured as an outcome of the rehabilitation. In conclusion, the recorded data on SEBAR in the first time hearing aid user group showed the ability of the advanced hearing aids in processing the time varying signals at the brainstem level.

SEABR at Lower intensity level

Another interesting finding from the study was the intensity level used to elicit the responses for SEABR. Intensity level of 60 dBnHL was used in order to justify the recorded SEABR that would reflect the conversational representation of speech at the brain stem level. To our knowledge, the current study could be the first one to focus on recording SEABR at the lower intensity level. The lower intensity level signal allows further postulation that SEABR can be used as an important tool in temporal processing research, as it would allow quantification of the neural encoding of speech sounds at the lower intensity level. This is an important factor to be considered and recommended with much of the SEABR studies in the literature having used supra threshold intensity levels *(Russo et al ,2004, Johnson et al, 2007, Vander Werff& Burns, 2011, Ahadi , Pourbakht, Jafari, &Jalaie, 2014).*

Thus, by the use of a lower intensity level, one can assess the speech through hearing aids at the impaired brain stem level. This further justifies the notion that older individuals repeatedly reported of speech perception difficulties at their lower intensity level and not at supra threshold levels. It is indeed a proven fact that the difficulties faced by these individuals could primarily be due to the vascular and other related changes in the cochlear structures, which would compromise the amplification process of the cochlea or impair the cochlear active processing. However, along with the existing theory and based on the current results, it could be stated that age related changes would also have detrimental effect on the stimulus transition processing from cochlea to central auditory level .Further, the impaired representation of the acoustic image would rather make it complex for the elderly in understanding speech as a whole, thus making the sub cortical speech processing an important gateway in speech perception *(Krishnan & Agarwal, 2010,Clinard& Tremblay,2013).*

In general, SEABR provides a unique window in understanding the encoding of complex speech sounds at the transition level. The current study is one of its kind in SEABR research of reporting the age related changes at the brain stem level in a more controlled manner. Much of the studies in literature have included the wider age range of comparing YA and OA. However, the present study delineates the timing changes occurring in the brain stem level from a varied spectrum of the adult population with adequate care taken in categorizing the adults into three groups, based on the age. Thus, the MA group was additionally incorporated in the study. Thus by focusing on the neural encoding of speech sounds, this study has tried to establish relevant facts previously found in behavioural measures regarding the impaired temporal processing or timing changes in signal processing seen in aging population .The findings for the OR and SR in all the 3 groups have provided enormous information on timing changes and its effect on age by using SEABR. It is presumed that the results of the present study would facilitate the scientific research community in establishing the facts on temporal processing in a more quantifiable manner.

Clinical Applications

The results of the current study provided information, applicable in hearing evaluation and aural rehabilitation. The SEABR measures in the various age groups provided the clinical insight on how the brainstem timing changes are represented by using SEABR. The usual and most common complaints often reported by millions of patient around the world were 'I can hear you but I can't understand your speech'. Most often, this particular complaint from the patient is overlooked by many clinicians in hearing assessment with the result of the end user deprived of the right answer from hearing professionals. The overall information from the current study emphasizes the importance of assessing temporal processing in elderly population by means of objective and more quantifiable measures, which would help the audiologist to probe further on the timing deficits reported by the patients.

It is felt that the results from the hearing aid user group of this study, would assist the clinicians in better hearing aid selection and fitting, thereby achieving the most important component in aural rehabilitation. The quantified and objective means of SEABR information would enable the audiologist to understand how the impaired auditory system processes the acoustically rich signals from the recorded response. It would allow the clinician to reprogram the hearing aid if required or alter the signal processing by selecting advanced hearing aids with additional acoustic features. The results would also be helpful for the hearing aid manufacturers to oversee the signal processing and acoustic representation of the speech sounds at the brain stem level, considered as the gateway towards the higher order processing, Thus, by combining the information obtained from the timing changes from the 3 normal hearing groups and the hearing aid user groups, this study has attempted to contribute to better audiological clinical practice and technologically superior hearing aids from the industry.