Hearing Aid Usage: Relationship Between Auditory Plasticity and Audiological Measures

[1]Pragati Rao M. V. & [2]Manjula P.

Abstract

The present study aimed to evaluate the effects of plasticity in behavioural and electrophysiological measures in naïve monaural hearing aid users before and after a period of hearing aid usage. Eight participants were evaluated in two phases, i.e., at the time of hearing aid fitting (baseline) and a follow-up after two to three months. Behavioural measures included aided and unaided speech identification scores (SIS) and signal-to-noise ratio 50 (SNR-50). Electrophysiological measures were unaided speech-evoked ABR and LLR. The results revealed no significant difference between baseline and follow-up evaluations for unaided SIS, SNR-50, amplitude and latency of peak V, P1, N1, P2, N2 in the unaided ear. However, in the aided ear, there was a significant difference between baseline and follow-up for unaided and aided SIS, aided SNR-50, amplitude of N1-P2 complex. Better synchronization of nerve fibres and acclimatization to listening to sounds at a higher presentation level might be the reasons for improvement noted in the aided ear. In the aided and the unaided ear, though changes were seen in the evoked potentials, no significant differences were noted. More changes were seen in the cortical potentials than the brainstem potentials. This information will be useful in counseling naïve monaural hearing aid users to wear their hearing aids for a longer time, use binaural hearing aids or to alternate the hearing aid between the two ears.

Keywords: *Acclimatization, SNR-50, speech-ABR, LLR*

Introduction

Hearing devices such as hearing aids and cochlear implants, help individuals with hearing impairment. Evidence from literature reflects that there is a lot of variability in performance with such devices across individuals (Tremblay, 2003). Kochkin (2003) has reported that over 16% of people receiving hearing aids completely rejected them, and only 60% are satisfied with their aids. Despite much research focusing on the technology used in such devices, research still cannot fully explain the reason for two individuals with the same configuration and degree of hearing loss demonstrating significantly different improvements in speech understanding with similar devices. One possible explanation for performance variability may lie beyond the ear, i.e., central auditory plasticity could be a factor (Tremblay, 2003).

Changes in performance are noticed when the individuals with hearing impairment start using their hearing aids for the first time. These changes in performance may be related to the two effects of plasticity namely, auditory acclimatization and auditory deprivation. The auditory acclimatization is defined as ‘a systematic change in auditory performance with time, linked to a change in the acoustic information available to the listener. It involves improvement in performance that cannot be attributed purely to task, procedural, or training effects’ (Arlinger et al., 1996, p.87S). While, auditory deprivation effect is the ‘systematic decrease, over time in auditory performance associated with the reduced availability of acoustic information.’ (Arlinger et al., 1996).

Plasticity implies a physiologic basis for change in auditory function due to auditory learning. Auditory learning is defined as a functional change in auditory ability for the better (acclimatization) or for the worse (deprivation). Acclimatization and deprivation can be characterized as components of auditory learning that are going in two different directions (Palmer, Nelson & Lindlay, 1998). Physiological plasticity of the auditory system is examined as the possible underlying mechanism for auditory learning that is measured through functional abilities.

Decrements in performance of the unaided ear in monaural hearing aid users have been reported by several investigators (Silman, Gelfand & Silverman, 1984; Gelfand, Silman & Ross, 1987; Hattori, 1993; Gelfand & Silman, 1993). Gatehouse (1989) reported that in monaural hearing aid users with symmetrical hearing loss, aided ear performs better at higher presentation levels whereas the unaided ear performs better at lower presentation levels. The intensity dependence suggests that an ear which is used to receiving a high level of stimulation, and hence the associated pattern of speech cues, will ‘adapt’ to the

[1]E-mail: pragatir@gmail.com; [2]Professor of Audiology, E-mail: manjulap21@hotmail.com

pattern of cues presented and be most efficient at analyzing at high presentation levels. It can be inferred from the findings of this study that the effects of deprivation and acclimatization might be noticed only at higher presentation levels. Hurley (1999) reported that deprivation effect required at least two years of monaural hearing aid usage.

Studies have reported improvements in speech measures over time (Cox, Alexander, Taylor & Gray, 1996; Arkis & Burkey, 1994). Following a period of hearing aid usage increased Uncomfortable Loudness Level (ULL) in the aided ear (Munro & Trotter, 2006), differences in loudness scaling (Philibert, Collet, Vesson & Veuillet, 2002; Philibert, Collet, Vesson & Veuillet, 2005), changes in intensity discrimination (Robinson & Gatehouse, 1996; Philibert et al., 2002, 2005), and changes in frequency discrimination (Gabriel, Veuillet, Vesson & Collet, 2006) have also been reported.

Philibert et al., (2005) reported shortening of wave V latency in the right ear in binaural hearing aid users. Munro, Pisareva, Parker and Purdy (2007) reported larger mean peak-to-peak amplitude of wave V to SN10 in the aided ear of long term monaural hearing aid users. Sakhuja, Munjal and Panda (2010) noted a significant decrement in the latencies and improvement in the amplitudes of BSER and MLR during the two month follow-up conducted in monaural hearing aid users. McCullagh (2009) found no significant differences between baseline and follow-up sessions for the Nonsense Syllable Test, N1 amplitude, P2 amplitude, and P2 latency between naïve hearing aid users and a control group who did not wear any amplification. However, statistically significant differences did exist for the change in N1 latency measure between the two groups.

As discussed above, there are abundant studies in literature that have evaluated the change in subjective measures following hearing aid usage (Cox & Alexander 1992; Cox et al., 1996). Other studies have focused on psychophysical measures (DLI, DLF) to evaluate plasticity following hearing aid usage (Robinson & Gatehouse, 1995, 1996). Several retrospective studies have evaluated physiological changes such as changes in ABR in fitting ear of adults (Hamilton, 2007 as cited in Munro, 2008; Munro et al., 2007). The present study is a prospective study to monitor the changes in behavioural measures and electro-physiological measures following hearing aid usage. The aim of the present study is to document the changes in behavioural and electro-physiological measures in monaural hearing aid users before and after a period of hearing aid usage. There were two main objectives of the study. The first objective was to compare the unaided performance on the measures such as speech identification scores (SIS), signal-to-noise Ratio-50 (SNR-50), auditory brainstem response (ABR), and auditory long latency responses (ALLR) in the unaided and aided ear at the time of baseline and follow-up evaluations. Another objective was to compare, the aided performance in speech identification scores (SIS) and signal-to-noise ratio-50 (SNR-50), the aided ear at the time of baseline and follow-up evaluations.

Method

Participants

Phase I: In total, 10 individuals between the age of 18 and 65 years (Mean=3.40 years, SD=14.62 years) participated in the study. The participants had bilateral moderate sensori-neural hearing loss. The hearing loss was symmetrical with a difference in pure tone average between the ears being less than or equal to 15 dB. Tympanometric findings fell within normal limits i.e., static compliance between 0.4 and 1.6 cc (Jerger, 1970) and peak pressure between-100 and 50 daPa (Jerger, 1970). The participants were fitted with an appropriate hearing aid and optimized such that the aided thresholds of all participants were within the speech spectrum from 500 Hz to 4000 Hz. Naïve hearing aid users were taken for the study. Aided speech identification scores were at least 80%. The participants did not have history of any neurological, cognitive, speech and language problems. Informed consent was obtained prior to data collection.

Phase II: Individuals who were evaluated in Phase I were evaluated again in Phase II, i.e., after two to three months of hearing aid usage. However, out of the ten individuals who participated in Phase I, eight individuals participated in Phase II. Attrition and lack of consistent hearing aid use were the major reasons for decreased number of participants in Phase II.

Stimulus Recording and Preparation

Three adult male speakers with normal voice whose mother tongue was Kannada (Dravidian language widely spoken in Karnataka, South India) were chosen to utter the Consonant Vowel (CV) token /da/ using normal vocal effort. Adobe Audition (V-3) software, installed in a personal computer was used to record and store the CV tokens. CV tokens were obtained using a microphone (Ahuja, AUD-101XLR) which was placed at a distance of 10 cm from the lips of the speaker. The test stimulus /da/ was a naturally produced voiced alveolar stop speech sound, in consonant-vowel combination. The total duration of /da/ was 49.71 ms with burst duration of 7.1 ms, CV boundary of 5.51 ms and the formant transition of 37.1 ms.

The recorded stimulus was digitized using a 32-bit processor at 44,100 Hz sampling frequency. A total of 3 CV /da/ stimulus (uttered from three speakers) tokens obtained were subjected to rating for naturalness and quality from 10 listeners with normal hearing. The token with the highest rating for goodness was selected to be used as the stimulus for recording the speech-evoked ABR and LLR.

Procedure

To document the changes in behavioural and electrophysiological measures in monaural hearing aid users following a period of hearing aid usage, the testing was conducted in two Phases. In Phase I, speech-evoked ABR and LLR measures were obtained in the unaided condition for the participants. In addition, behavioural measures such as speech identification scores (SIS) and the Signal-to-Noise Ratio-50 (SNR-50) i.e., the difference in intensity between the speech and speech noise needed for correct repetition of at least 50% of the phonemically balanced words, were obtained.

To evaluate the change in performance, the measures obtained in Phase I (speech-evoked ABR, LLR, SIS & SNR-50) were repeated in Phase II. At the time of testing for Phase II, the participants had used the hearing aid for at least two to three months and had a self-reported hearing aid usage of at least 5-6 hours per day (range 5- 9 hours per day) .

Phase I: Baseline evaluation

Baseline evaluation was performed at the time when the participant came to collect his/her hearing aid. Electrophysiological measures and behavioural measures were obtained.

Electrophysiological measures - ABR and LLR A new session for each participant was created in the patient's demographics of the Bio-Logic Navigator Pro. After obtaining the required skin impedance, disc type silver electrodes coated with conduction gel were placed in vertical montage.

The stimulus /da/ was presented through the insert receiver to the participant, who was seated in an air-conditioned sound-treated room. The stimulus and recording parameters for speech evoked ABR and LLR are given in Table 1. At least two recordings were obtained for both ABR and LLR. Weighted average of the recordings was taken. The latency of wave V, P1, N1, P2 and amplitude of wave V and the N1-P2 complex in the two recordings were identified, and marked visually by three experienced audiologists. The latencies of the peaks, as identified by the three audiologists were tabulated for wave V, P1, N1, and P2.

Analysis of frequency following response (FFR) waveforms: Additionally, to know the different aspects of speech i.e., the coding of fundamental frequency, first formant frequency and higher harmonics, an FFT analysis of the sustained response of the speech evoked ABR was done. This was executed using the MATLAB R 2009a platform and software (Brainstem toolbox) developed by Kraus (2004) at Northwestern University. Fourier analysis was performed on the 12 to 53 ms epoch of the frequency following response (FFR).

Information regarding the coding of fundamental frequency, first formant frequency and higher harmonics was extracted in order to assess the amount of activity occurring over all these three frequencies. Activity occurring in the frequency range of the response corresponding to the fundamental frequency of the speech stimulus (103-130 Hz), first formant frequencies of the stimulus (455-580 Hz) and for the higher harmonics (585-1200 Hz) was measured for all the participants. To avoid the spectral splatter, a 2 ms 'on' and a 2 ms 'off' Hanning ramp was applied to all the waveforms. Zero-padding was employed to increase the number of frequency points where spectral estimates were obtained.

An auditory evoked response from the participants is required to be above the noise floor in order to be included in the analyses (Russo, Nicol, Musacchia & Kraus, 2004). This calculation is performed by comparing the spectral magnitude of the pre-stimulus period to that of the response (Russo et al., 2004). If the quotient of the magnitude of the F0, F1 and higher harmonics frequency component of the FFR divided by that of the pre-stimulus period was greater than or equal to one, the response was deemed to be above the noise floor (Russo et al., 2004). If the response amplitude was above the noise floor, the raw amplitude values of the F0, F1 frequency and higher frequency component of the FFR were then measured and noted. The same procedure was followed for each participant.

Behavioural measures

Speech identification scores: In the unaided and aided conditions, speech identification scores were obtained in sound field using the PB bisyllabic word lists in Kannada (Yathiraj & Vijayalakshmi, 2005). The presentation level was 40 dB SL (re: SRT) in the unaided condition and at 45 dB HL in the aided

Table 1: Stimulus and recording parameters used for recording ABR and LLR

	ABR	LLR
Stimulus parameters		
Stimulus	Speech stimulus /da/ of 49.71 ms	Speech stimulus /da/ of 49.71 ms
Polarity	Alternate	Alternate
Number of sweeps	2000	200
Stimulus rate	5.1/second	1.1/second
Intensity	80 dBnHL	80 dBnHL
Transducer	ER 3A insert receiver	ER 3A insert receiver
Recording parameters	**ABR**	**ALLR**
Mode of stimulation	Monoaural	Monoaural
No. of channel	One channel	One channel
Electrode montage	Vertical Montage Fz: Non-inverting electrode Non test ear: Ground electrode Test ear: Inverting electrode	Vertical Montage Fz: Non-inverting electrode Non test ear: Ground electrode Test ear: Inverting electrode
Filter setting	100 to 3000 Hz	0.1 to 30 Hz
Amplification	1,00,000	50,000
Notch filter	On	-
Recording time window	- 15 to + 83.3 ms	-30 to +533 ms
Replicability	Twice	Twice

condition. Speech stimuli were presented using monitored live voice and routed through the loudspeaker of the audiometer. The loudspeaker was situated at a distance of one meter and at an azimuth of 45 degrees from the test ear. The number of words repeated correctly, out of 25 words in the list, was noted as the speech identification scores in the unaided and aided conditions.

Speech recognition threshold in noise to obtain signal-to-noise ratio-50 (SNR-50): SNR-50 was obtained by determining the difference in intensity of the speech and the intensity of speech noise, in dB, when the participant correctly repeated at least two out of four words presented.

The participant was seated in an air-conditioned sound-treated room. Both speech and speech noise were presented through the same loudspeaker at 45 degrees azimuth from the test ear. An adaptive procedure was used to obtain SNR-50 for each participant in the unaided and aided conditions. The unaided and aided SNR-50 was obtained with the monitored live speech signal presented at a constant level of 45 dBHL. The level of the noise was varied with the initial level being 30 dB HL, i.e., 15 dB less than the level of speech. The participant was instructed to repeat the words heard. The noise level was increased in 5 dB steps until the participant obtained a score of 50%. From this point, the noise was varied, either increased or reduced in 2 dB steps so as to obtain a 50% correct word recognition score for determining SNR-50. The difference between the level of the speech and the speech noise, at this stage, was noted as the SNR-50.

Phase II: Testing after a period of hearing aid usage

Follow-up assessment of participants of Phase I was carried out. The participants had a self reported hearing aid usage of at least 5 to 6 hours per day. Electrophysiological and behavioural measures were assessed using a similar procedure as in Phase I.

Results and Discussion

Descriptive statistics and analysis of variance (ANOVA) were carried out on the data collected to evaluate the objectives.

Speech Identification Scores (SIS)

Descriptive statistics was used to find out the mean and standard deviation. Table 2 depicts the mean and standard deviation for the raw scores obtained for unaided and aided SIS at the time of baseline and follow-up.

Table 2: Mean and Standard Deviation (in parenthesis) for the raw unaided and aided speech identification scores during the baseline and follow-up evaluations

Measure	Aided Ear		Unaided ear	
	Base-line	*Follow-up*	*Base-line*	*Follow-up*
Unaided SIS	21.63 (1.85)	22.38 (1.85)	21.00 (1.93)	21.13 (2.17)
Aided SIS	22.6 (1.60)	23.5 (1.39)	-	-

Two-way repeated measures ANOVA was done to compare the unaided performance in the unaided and aided ear for the speech identification scores (SIS), at the time of baseline evaluation and after a period of two to three months (follow-up). Interaction between the evaluations (baseline & follow-up) and conditions (aided & unaided ear) was statistically significant [F(1, 7)=0.011; p<0.01]. Hence, the data were subjected to paired t-test. Statistically significant difference was not present between the two evaluations for the unaided ear. However, in the aided ear, the follow-up evaluation revealed a significant improvement in speech identification scores [t(7)=3.00; p<0.05]. This finding is in consonance with that reported by Gatehouse (1992) and Arkis and Burkey (1994) who reported that the mean word recognition scores remained stable in the unaided ears but improved for the aided ears.

The speech identification scores are measured at supra-threshold level. It can be postulated that aided ears acclimatize to the higher sound levels due to amplification and hence perform better on the supra-threshold task. Gatehouse (1989) has reported that at higher presentation levels, the aided ear performs better than the unaided ear.

To compare, the aided performance in the aided ear for the speech identification scores (SIS) at the time of baseline and follow-up evaluation, paired t-test was done. Statistically significant difference was noted between the two evaluations [t(7)=2.83; p<0.05] with the SIS after a period of hearing aid usage being better than at the baseline. This finding is supported by the findings reported by Cox et al., 1996 who have also reported improvement in speech intelligibility measures for the aided condition over time.

Signal-to-Noise Ratio-50 (SNR-50)

Descriptive statistics was used to find out the mean and standard deviation of SNR-50 during baseline and follow-up evaluations. Table 3 depicts mean, standard deviation (SD) for unaided and aided SNR-50 values during the baseline and follow-up evaluations.

Table 3: Mean and Standard Deviation (in parenthesis) for unaided and aided SNR-50 values during the baseline and follow-up evaluations

Measure	Aided Ear		Unaided ear	
	Base-line	Follow-up	Base-line	Follow-up
Unaided SNR-50 (dB)	4.20 (5.83)	-0.25 (5.65)	5.40 (5.56)	2.75 (5.18)
Aided SNR-50 (dB)	4.75 (3.11)	0.50 (3.16)	-	-

To compare the unaided performance in the unaided and aided ear for SNR-50, at the time of baseline evaluation and follow-up evaluations non-parametric Wilcoxon Signed Ranks test was used. This was done as there was a large variability in the data obtained as can be seen in Table 3. Statistically significant difference was not seen in the unaided SIS for the unaided ear [Z=0.42; p>0.05] and the aided ear [Z=1.53; p>0.05]. However, SNR-50 was better in the follow-up evaluation compared to the baseline evaluation. Silman, Silverman, Emmer, and Gelfand (1993) found that speech performance in noise worsened from the test to re-test in the unaided ear and improved from test to re-test in the aided ear, but there was no significant difference between initial and follow-up testing. Initial testing was done 6 to 12 weeks post hearing aid fitting and follow-up was done one year after initial testing. Similar results were reported by Bentler, Niebuhr, Getta, and Anderson (1993) in a follow-up study. No significant improvement in Hearing in Noise test and Nonsense syllable test scores in noise was seen 1, 3, 6 and 12 months post hearing aid fitting. However, visual inspection of the raw data indicated an improvement in scores between initial testing and follow-up at one month. Taken together, these findings suggest that though there may be a difference in the aided ear, a significant difference may not be noted. It could be hypothesized that longer duration of hearing aid usage could result in more apparent differences between the aided and unaided ear.

To compare the aided performance for SNR-50 during the two evaluations, Wilcoxon Signed Ranks test was used. It was noted that the individuals required a lower SNR in the follow-up evaluation and this difference was statistically significant [Z=0.763; p<0.05]). Gatehouse (1992) also reported a benefit in signal-to-noise ratio in the aided ear of monaural hearing aid users 6 to12 weeks post-hearing aid fitting. This could be because an individual becomes more accustomed to the amplified sound through the hearing aid

(Gatehouse, 1992) and therefore, better performance is seen after a period of hearing aid usage.

Speech-Evoked ABR

A clear, replicable wave V could be visually identified in only four out of eight of the participants. Therefore, Wilcoxon Signed Ranks test was used to compare the two evaluations. Table 4 depicts the mean and standard deviation for latency and amplitude of V peak. The Z values obtained from the Wilcoxon Signed Ranks test are also given.

A slight delay in the latency of V peak was seen for the unaided ear during the follow-up evaluation when compared to the baseline evaluation. Whereas, a slightly earlier peak V was seen on follow-up for the aided ear. However, the difference between baseline and follow-up evaluations was not statistically significant in the unaided as well as the aided ears ($p>0.05$). There are mixed results in literature too regarding hearing aid usage and ABR measures. Munro et al. (2007) have also reported similar latency values for click-evoked ABR in the fitted and non-fitted ears, in listeners with at least two years of monaural hearing aid experience.

In the present study, a slight decrease in the amplitude of wave V for the unaided ear was noted at the follow-up evaluation. Also, a slight increase in the amplitude of wave V for the aided ear was seen at follow-up. These differences were not statistically significant ($p>0.05$). Munro et al. (2007) reported an increase in the mean amplitude of wave V to SN-10 for the fitted ear with at least two years of hearing aid usage. Changes with presentation level were also reported suggesting intensity dependence of plasticity effects. Sakhuja et al., (2010) reported shortening of wave V as well as increase in amplitude following monaural hearing aid usage. Philibert et al., (2005) found shortening of wave V latency only for the right ear in bilateral hearing aid users.

Absence of visually identifiable wave V in some of the participants in the present study may be related to the stimulus characteristics, degree of hearing loss and the age of the individuals. For those individuals in whom wave V could be identified, an increase in amplitude and a slight decrease in latency was noted for the aided ear. Probably with longer duration of hearing aid usage these changes may become more apparent or the changes may even saturate.

Information regarding the coding of fundamental frequency, first formant frequency and higher harmonics was extracted using FFT in order to assess the amount of activity occurring over all these three frequencies. Table 5 depicts the mean and standard deviation for the amplitude of fundamental frequency (F0), first formant (F1) and higher harmonics. Due to the large variability seen in the data Wilcoxon Signed Ranks test was used to compare F1 amplitude and

Table 4: Mean, Standard Deviation (in parenthesis), and Z values for latency and amplitude of wave V, in aided and unaided ear, during the baseline and follow-up evaluation

Parameter	Unaided Ear			Aided Ear		
	Baseline	Follow-up	Z	Baseline	Follow-up	Z
Latency (ms)	8.56 (3.80)	9.16 (4.97)	0.53	8.79 (2.92)	8.30 (2.82)	1.76
Amplitude (µV)	0.29 (0.12)	0.27 (0.10)	0.18	0.22 (0.06)	0.24 (0.03)	0.41

Table 5: Mean, Standard Deviation (in parenthesis), and Z values for amplitude of F0, F1 and higher harmonics in aided and unaided ear during the baseline and follow-up evaluations.

Parameter	Unaided Ear			Aided Ear		
	Baseline	Follow-up	Z	Baseline	Follow-up	Z
F0 Amplitude	5.27 (1.81)	4.97 (2.57)	-	5.50 (4.61)	6.09 (2.33)	-
F1 Amplitude	0.79 (0.32)	1.03 (0.54)	1.82	0.71 (0.29)	0.72 (0.26)	0.14
Higher harmonics amplitude	0.34 (0.10)	0.33 (0.08)	0.28	0.30 (0.09)	0.34 (0.07)	1.40

higher harmonics amplitude across baseline and follow-up evaluations for the two ears. The Z values obtained on comparing the baseline and follow-up evaluations F1 amplitude and higher harmonics amplitude are also given in table 5. Two way repeated measure ANOVA was used to compare F0 amplitude across the two evaluations [$F(1, 7)=0.02$; $p>0.05$).

Statistically significant difference was not seen for any of the parameters (F0, F1 and higher harmonics amplitudes) in any of the conditions or evaluations. A thorough survey of the literature did not reveal any study using speech-evoked ABR for evaluating plasticity and/or acclimatization effects in hearing aid users. FFR coding is impaired in sensori-neural hearing loss and second formant information is not encoded (Plyler & Ananthanarayan, 2001). In the present study, F0 coding was preserved in the participants and poor encoding of F1 and higher harmonics was seen. Preserved sustained brainstem responses in mild to moderate sensori-neural hearing loss has also been reported by Sumesh and Barman (2007).

Speech-Evoked LLR

ALLR was also done at the two evaluations and P1, N1, P2, N2 peaks were visually identified. Table 6 depicts mean and standard deviation for latency and amplitude of each of the peaks.

Two-way repeated measures ANOVA was done to compare the P1 latency during the two evaluations for both the ears. There was statistically no significant difference in the two ears between the two evaluations [$F(1, 7)=1.30$; $p>0.05$]. However, on close observation, it can be noted that the latency of P1 for the unaided ear is more prolonged than in the aided ear at the follow-up evaluation.

Due to high variability in the data obtained for P1 amplitude, Wilcoxon Signed Ranks test was used. There was statistically no significant difference in the amplitude for the unaided ear [$Z=0.56$; $p>0.05$]. As compared to the baseline evaluation, a statistically significant decrease in amplitude of P1 was noted for the aided ear [$Z=2.1$; $p<0.05$].

No significant difference was noted for amplitude and latency of N1, P2 and N2 between the two evaluations. However, paired t-test for N1-P2 amplitude revealed a significant increase in the N1-P2 amplitude in the aided ear as compared to the unaided ear [$t(7)=4.66$; $p<0.005$]. Seven out of eight participants wore hearing aids on the left side. Paired t-test, comparing the performance of left and right ears for the seven individuals, revealed a significant increase in the N1-P2 amplitude for only the left ear at follow-up evaluation only [$t(6)=4.99$; $p<0.005$.

There was no difference between the two ears at the baseline evaluation [t(8=0.77; $p>0.05$]. This suggests that the changes seen in N1-P2 amplitude was not due to auditory pathway asymmetry as reported by Philibert et al., (2005).

Table 6: Mean and Standard Deviation (in parenthesis) for latency and amplitude of P1, N1, P2, and N2 in aided and unaided ear during the baseline and follow-up evaluations.

Parameter		Unaided Ear		Aided Ear	
Measure	Peak	Baseline	Follow-up	Baseline	Follow-up
Latency (ms)	P1	47.66 (8.68)	67.09 (41.84)	44.43 (4.36)	52.15 (17.29)
	N1	95.29 (14.02)	116.99 (42.66)	99.27 (19.30)	99.95 (19.12)
	P2	187.92 (33.62)	208.80 (29.60)	181.43 (31.42)	187.79 (24.21)
	N2	303.36 (41.69)	311.92 (31.71)	293.34 (47.09)	289.74 (38.66)
Amplitude (µV)	P1	1.37 (1.19)	1.19 (0.98)	1.46 (1.11)	1.00 (1.10)
	N1	3.77 (1.62)	3.35 (1.62)	3.67 (1.83)	4.12 (1.66)
	P2	2.92 (2.30)	2.74 (1.87)	3.29 (2.31)	2.90 (2.04)
	N1-P2	6.69 (3.33)	6.08 (3.11)	6.93 (3.52)	7.90 (3.66)
	N2	0.83 (1.12)	0.86 (0.72)	1.21 (1.11)	0.49 (0.56)

Two-way repeated measures ANOVA for N2 latency revealed no significant difference between the two evaluations for both ears [F(1,7)=0.04; p>0.05]. Due to high variability in the data, Wilcoxon Signed Ranks test was used to compare the amplitude of N2. There was no statistically significant difference between the two evaluations for the amplitude of N2 for the aided ear [Z=0.56; p>0.05] and the unaided ear [Z=1.68; p>0.05].

Inconsistencies in the behavioural and electro-physiological findings following hearing aid usage has been reported in literature (McCullagh, 2009). Even though participants showed an improvement in measures of speech intelligibility following hearing aid usage, similar changes in electrophysiological measures was not evident. There is paucity of research assessing plasticity changes using electrophysiological measures following hearing aid usage. The N1-P2 complex is thought to reflect synchronous neural activation of structures in the thalamic-cortical segment of the central nervous system in response to auditory stimulation (Naatanen & Picton, 1987). Significant increase in the N1-P2 complex amplitude for the aided ear reflects greater synchronization in the structures due to introduction of new amplified signal. Also, experience-induced changes can be reflected in the N1-P2 complex (Ponton et al., 2001; Tremblay, Kraus, McGee, Ponton & Otis, 2001). Auditory pathway asymmetry cannot be used to explain the changes seen in the aided ear of the individuals as no difference was found between the two ears at baseline evaluation. Therefore, the changes in N1-P2 amplitude may be taken to be evidence for changes due to experienced induced plasticity.

In the present study, more changes were noticed in the cortical potentials than in the brainstem potentials. This suggests that plasticity occurs earlier/ may be more evident in cortical than in brainstem structures. Madhok and Maruthy (2010) also noted earlier and larger changes in cortical than brainstem potentials following training in individuals with normal hearing. They attributed these changes to difference in the number of cortical and brainstem neurons. Higher number of neurons in the cortex could result in greater scope for neural arborization and in turn plasticity. Statistically, no significant changes were seen in any other latency or amplitude measure (except P1). This finding is in consonance with McCullagh (2009) who reported changes only in N1 latency. However, it should be kept in mind that amplitude measures are more susceptible to fluctuations in signal-to-noise ratios during different test sessions (Munro et al., 2007). A slight prolongation of all peaks in the unaided ear as against stability of latencies in the aided ear could be an indicator towards early onset of auditory deprivation. It could be that the amplification period was not long enough to elicit more pronounced changes in the aided ear.

Conclusions

There is a paucity of research in evaluating changes due to plasticity in behavioural and electro-physiological measures in naïve hearing aid users. The present study aimed to shed more light in this area of research. The most significant finding of the study was the change seen in N1-P2 amplitude between the two evaluations. This implies that longer duration of hearing aid usage can result in further improvement in the performance of the aided ear. This finding can be useful in counselling individuals with hearing impairment towards using their hearing aids for longer periods of time during the day. Although not statistically significant, close observation of the data revealed that the unaided ear performed poorer on all the measures. It could be speculated that the performance of the unaided ear might worsen more if amplification is not provided, suggesting a possible deprivation effect. Therefore, this finding may be used to counsel individuals with aidable hearing-impairment, to use binaural hearing aids or to at least alternate the hearing aid between the two ears on a regular basis. The findings of this study can also be used to counsel naïve hearing aid users who have difficulty in adjusting to amplification. The brain requires time to adjust to amplification i.e., Hearing Aid Brain Rewiring Accommodation Time (Gatehouse & Killion, 1993). Therefore, hearing aid users may be motivated to start using their hearing aid for increasingly longer periods of time in order to obtain more benefit. A common problem in individuals with hearing impairment understands speech in the presence of background noise. Kochkin (2002a) reported that only 30% of the hearing aid users were satisfied with their hearing aids in noisy situations. Kochkin (2002b) also reported that better speech understanding in the presence of background noise is the highest improvement desired by hearing aid users. The findings of the present study reveal that there was a significant improvement in aided SNR-50 following a period of hearing aid usage. Consistent hearing aid usage could lead to larger improvements in SNR and therefore could result in more satisfaction with the hearing aid. This finding too would be useful while counselling a naïve hearing aid user.

Acknowledgements

The authors acknowledge with gratitude Director, All India Institute of Speech and Hearing, Mysore for permitting to conduct the study at the institute. The authors thank the HOD-Audiology, for permitting to use the equipment in the department. The authors wish to thank the staff of dept of Audiology and all the participants for their cooperation.

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