Effect of Reverberation on Acceptable Noise Level in Individuals with Normal Hearing and Hearing Impairment

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Abstract

In the present study, the effect of changes in reverberation time on acceptable noise level in individuals with normal hearing and hearing impairment was investigated. The speech material for establishing acceptable noise level were digitally modified to create four reverberant conditions by applying different values of reverberation time (RT) to a non-reverberant condition (RT : 0, 0.4, 1.2, and 2 seconds). Two groups of 15 participants each (18-50 years) participated in the study; Group I had individuals with normal hearing, and Group II had individuals with bilateral mild- moderately severe hearing impairment, who had no previous experience with any amplification devices. Most comfortable listening level and background noise level measurements were established in each reverberant condition, and from these measurements, acceptable noise levels (ANLs) were calculated. In individuals with normal hearing, significant difference was found between ANL for non-reverberant stimuli and that for stimuli with RT of 2 seconds. This can be attributed to the unfavorable influence of reverberation on the primary talker, which might have interfered with the listeners' willingness to accept background noise. The ANLs of participants with normal hearing were better than aided and unaided ANLs of those with sensorineural hearing loss indicating the adverse effect of reverberation and noise on ANLs in participants with hearing impairment. The aided and unaided ANLs were significantly different, with a better value for aided ANL. This is clinically relevant as ANLs can be used to predict success with hearing aid.

Keywords: *Most comfortable listening level, background noise level, reverberant stimuli, sensorineural hearing loss.*

Introduction

Speech is seldom transmitted in a totally quiet, echo-free environment. Typically there are several degrading factors that can interact with each other to impede effective communication of speech. These factors include competing background noise, room reverberation, distance between speaker and listener, reduced hearing sensitivity, auditory processing abilities of the individual, etc.

Reverberation refers to the persistence or prolongation of sound within an enclosure as sound waves reflect off hard surfaces (Lochner & Burger, 1964; Nabelek & Pickett, 1974). Reverberation is present in all enclosed spaces to some degree (Lochner & Burger, 1964; Crandell & Smaldino, 2000). Reverberation is caused when reflections of sound waves of nearby surfaces create additional sound waves that overlap with the original signal. Reverberation time (RT) is defined as the time (seconds) it takes for the sound from a source to decrease in level by 60dB after the source has stopped (American National Standards Institute, 1970). A decrease of 60 dB represents a reduction of 1/1,000,000 of the original intensity of the sound. A longer RT results in more perceived reverberation, or echo on the part of the listener and has been well documented to produce a decrease in speech intelligibility (Houtgast & Steeneken, 1973; Duquesnoy & Plomp, 1980). Reverberation causes a prolongation of the spectral energy of the vowel sounds, which masks succeeding consonant phonemes, especially those consonants in word final positions. The masking effect of reverberation is more noticeable for vowels than for consonants because vowels exhibit greater overall power and are of longer duration than consonants. In effect, the distinct phonemes of speech become more difficult to discern, and the speech is therefore more difficult to understand (Houtgast & Steeneken, 1973). In highly reverberant environments, words may actually overlap with one another, thus causing reverberant sound energy to fill in temporal pauses between words and sentences.

Reverberation is more unfavorable when it occurs in combination with background noise than when present in isolation. Most listening situations have some noise and some degree of reverberation. When noise and reverberation are combined (as occurs frequently in actual listening situations) even younger listeners with normal auditory systems experience difficulty with speech understanding (Moncur & Dirks, 1967; Nabelek & Pickett, 1974).

The major sequelae of sensorineural hearing loss (SNHL) are speech perception difficulties, particularly in noisy or reverberant listening environments. Studies have noted marked variability on tasks of speech perception in reverberation, particularly among hearing-impaired (Nabelek & Pickett, 1974). As reverberation is not often confronted in the absence of background noise, it is important to evaluate amount of background noise that an individual would accept while listening to speech in reverberant conditions. Also, studies

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have shown weak correlations between speech in noise scores, subjective evaluations of communication skills and hearing aid outcome. The acceptable noise level (ANL) measurement was first developed to quantify the amount of background noise an individual would accept while listening to continuous discourse (Nabelek, Tucker & Letowski, 1991).

According to Nabelek et al. (1991) to measure ANL, the listener's most comfortable listening level (MCL) for running discourse is measured. Next, the background noise level (BNL) is measured as the amount of background noise the individual is willing to accept while listening to the primary speech stimulus at MCL. Subtracting BNL from MCL gives ANL. The ANL measure assumes that speech understanding in the presence of noise may not be as important as the willingness to listen in the presence of noise.

Studies show that ANL is not related to hearing sensitivity (Nabelek, Tampas & Burchfield, 2004), gender (Rogers, Harkrider, Burchfield & Nabelek, 2003), and age (Nabelek, Freyaldenhoven, Tampas, Burchfield & Muenchen, 2006). ANL remains relatively constant when fitted with monaural or binaural amplification (Nabelek et al., 1991). Nabelek et al. (1991) found that ANL did not vary with different types of background noise. They used multi-talker babble, speech-spectrum noise, traffic noise, noise of a pneumatic drill, and music as background noise. Of the background noises used, music was the only one which showed significant effect. This is due to the variability of the music sample, the frequency spectrum of the music sample, and/or the listener's preference for the music sample. Plyler, Madix, Thelin and Johnston (2007) investigated the influence of high frequency information (i.e., beyond 2000Hz) on ANLs in individuals with normal hearing and impaired hearing. They reported that information beyond 2000 Hz may change (i.e., improve or degrade) some listeners' acceptance of background noise.

Studies which have been conducted to examine the physiological correlates of ANL suggest that ANL may be mediated by non-peripheral factors; it may be mediated, in part, beyond the level of the superior olivary complex where binaural processing initially occurs within the central auditory nervous system (Harkrider & Smith, 2005). Nabelek et al. (1991) speculated that ANL may be inherent to the individual.

Adams, Gordon-Hickey, Moore and Morlas (2010) evaluated the effects of reverberation on ANL in younger and older adults with normal hearing sensitivity. The results revealed no significant effect for age and/or reverberation time on MCL or ANL findings.

However, previous researches have not specifically examined how the presence of reverberation changes a hearing impaired individual's preferred listening level for speech, and the acceptance of noise. This is an important consideration as most listening environments are degraded by both noise and reverberation and the detrimental effect of combination of noise and reverberation affects individuals with hearing impaired more adversely than those with normal hearing. Therefore, the aim of the present study was to investigate the effect of reverberation and changes in reverberation time on ANL in individuals with normal hearing and hearing impairment. The study compared the effect of changes in reverberation time on ANL in individuals with hearing impairment under unaided and aided conditions. Unaided and aided ANL of individuals with hearing impairment were separately compared with the ANL of individuals with normal hearing.

Method

Participants

Thirty participants in the age range of 18 to 50 years were included in the study. They were divided into two groups; first group included fifteen individuals with normal hearing and second group included fifteen individuals with bilateral mild to moderately severe sensorineural hearing loss who had no previous experience with any amplification devices. All were native speakers of Kannada language. All the participants had speech identification scores of > 75% in both ears and negative history of middle ear infections, active speech and language disorder, and neurologic disorder or any cognitive listening deficits. They did not have any illness on the day of testing. Prior permission was taken from all the participants for their willingness to participate in the study.

Speech Material

The speech material used for determining ANL procedure were three standardized passages in Kannada compiled by Savithri and Jayaram (2005) and one passage developed by Sairam and Manjula (2002) which were spoken with normal vocal effort by a native female speaker of Kannada. Using this material, four experimental conditions were created, with varying amounts of reverberation. The unaltered condition had no reverberation (NR), while the remaining three conditions had varying amounts of digitally added reverberation created by applying RTs of 0.4 second (RT1), 1.2 seconds (RT2) and 2 seconds (RT3) to the NR stimuli which was accomplished by using Adobe Audition 1.5 multi-track sound editing software. The parameters like, the attack time and the high frequency absorption times were kept constant for all the three conditions of reverberations. These speech materials (primary talker) were recorded onto a Sony compact disc and were played through a personal computer, whose output was routed through the auxiliary input of the double channel audiometer. The speech material was presented through one channel of the audiometer at 0 azimuth.

Kannada speech babble developed by Anitha (2003) which was recorded onto a Sony compact disc was used as the background competing stimulus in the study. This was played through a personal computer, whose output was routed through the auxiliary input of the double channel audiometer. The speech babble was presented through the other channel of the audiometer at 180 azimuth.

Test Procedure

Preliminary procedures included otoscopy, and a behavioral audiometric evaluation. The audiometric testing was performed using a double channel audiometer calibrated according to ANSI S3.6 (1996) standards. Speech recognition thresholds and speech identification scores were also obtained. All testing was carried out in a double-room sound treated environment, with ambient noise level in the permissible limits as per ANSI S3.1 (1999).

To determine ANL, the conventional procedure (Nabelek et al., 1991) that involved the tester adjusting the level of the test words to the most comfortable listening level (MCL) of the participant was employed. The measures of MCL were obtained using a three part bracketing procedure. The primary discourse was presented at 30 dB HL and increased in 5 dB steps until the participant indicated that the speech was louder than the participant would want to listen to it. The primary discourse was then reduced in 5 dB steps until the participant indicated that the speech was "too soft." From this level, the level of the story was adjusted until the subject found his most comfortable listening level or the level he would want to "listen to the story on the radio." The primary discourse was then adjusted up and down in 2 dB steps until accurate MCL was established. After establishing MCLs, the BNLs were determined. The passages were played at the level of the MCL of the subject through loudspeakers at 0 azimuth and simultaneously, multitalker babble was presented through loudspeakers at 180 azimuth. The presentation level of the multitalker babble was 30dB HL and its level was increased by 5dB steps until a point at which the participant was willing to accept the noise without becoming tired or tensed while listening to and following the words of the passage. The noise was next adjusted up and down in 2 dB steps until the participant indicated that the 12-talker babble was at the highest level that was acceptable while listening to the story without becoming tired or tense. The maximum level at which he or she could accept the noise without becoming tired or tensed was considered as the BNL. The ANL (dB) was calculated as the difference between MCL (dBHL) and BNL (dBHL) for each participant. ANLs were calculated for individuals with normal hearing (ANL1) as well as for those with hearing impairment in unaided (ANL2) and aided (ANL3) conditions for non reverberated as well as for different reverberated stimuli. The aided ANLs were established after fitting the participants of the second group with a 5 channel digital behind the ear hearing aid which had a fitting range of mild to severe degree of hearing loss. Presentation of the reverberant condition was randomized for each participant. Additionally, rest periods was given to the participants as needed. The randomization and rest periods served to reduce the likelihood of practice or fatigue effects.

Results and Discussion

Effect of Reverberation on ANL in Participants with Normal Hearing (Group I)

Descriptive statistics was done to calculate the mean and standard deviation (SD) of MCL, BNL and ANL of individuals with normal hearing under different reverberant conditions. Table 1 shows the mean and standard deviation (SD) of MCL, BNL and ANL of participants

Table 1: Mean and Standard Deviation (SD) of MCL, BNL and ANL of Participants of Group I under Different Reverberant Conditions

	RT (seconds)	Conditions	Mean (dB)	SD
	NR	MCL	43.13	05.32
		BNL	36.20	05.80
		ANL1	06.93	03.45
	RT1	MCL	43.73	04.61
Group I (N=15)		BNL	37.13	04.75
		ANL1a	06.60	04.10
	RT2	MCL	45.27	04.67
		BNL	36.00	05.10
		ANL1b	09.27	05.12
	RT3	MCL	46.33	04.82
		BNL	33.53	05.77
		ANL1c	12.80	05.17

Table 2: Mean and Standard Deviation (SD) Of MCL, BNL and ANL of Participants of Group II under Non - Reverberant and Different Reverberant Conditions

	RT (seconds)	Conditions	Parameter	Mean(dB)	SD
Group II (N=15)	NR	Unaided	MCL	54.27	06.49
			BNL	42.47	06.79
			ANL	11.80	06.11
		Aided	MCL	43.13	04.31
			BNL	32.40	05.18
			ANL	10.73	04.88
	RT1	Unaided	MCL	54.07	06.04
			BNL	41.20	06.25
			ANL	12.87	04.96
		Aided	MCL	42.80	03.91
			BNL	34.20	03.99
			ANL	08.60	04.42
	RT2	Unaided	MCL	57.53	06.01
			BNL	38.60	06.23
			ANL	18.93	05.44
		Aided	MCL	47.13	04.26
			BNL	31.27	05.70
			ANL	15.87	05.66
	RT3	Unaided	MCL	63.47	05.63
			BNL	35.47	05.96
			ANL	28.00	04.05
		Aided	MCL	50.67	04.32
			BNL	29.73	05.16
			ANL	20.93	05.47

of Group I under different reverberant conditions.

In the present study, the ANLs varied from 3 to 14 dB with a mean (SD) of 6.93 dB (3.45) for non - reverberant stimulus. From Table 1, it can be observed that the mean ANL for non reverberant condition (ANL1) in individuals with normal hearing was 6.93 dB. The mean ANL for RT of 0.4 seconds (ANL1a), 1.2 seconds (ANL1b) and 2 seconds (ANL1c) were 6.60 dB, 9.27 dB and 12.80 dB respectively.

Repeated measure ANOVA was done to find out within condition effects of participants in Group I. Significant difference was noticed with $F(3, 42) = 32.066$, $p< 0.01$. Multivariate ANOVA was done to find out between condition effects of participants in Group I. Significant difference was noticed with $F(3, 12) = 37.635$, $p< 0.01$. In both the cases, Post hoc analysis was administered and the result showed significant difference between the conditions at $p< 0.01$ level.

Significant difference was found between ANL for non-reverberant stimulus and that for stimulus with RT of 2 seconds. The ANLs for stimuli with RT of 0.4, 1.2 and 2 seconds were significantly different from each other. But, ANLs for non- reverberant stimulus was not significantly different from ANL for stimulus with RT of 0.4 seconds. Even though the mean ANL for the stimulus with RT of 1.2 seconds was greater than that for the non-reverberant stimulus, there was no significant difference between the two conditions.

Gordon-Hickey and Moore (2008) reported that small, but significant changes in ANL occurred with a reduction in intelligibility of the primary discourse. The primary talker conditions in their study included the Arizona Travelogue with forward presentation (intelligible), reversed presentation (unintelligible), and Chinese discourse (unintelligible to study participants). The unintelligible conditions resulted in an increase in ANL of 1.5 to 2.2 dB. This finding is in contrary to other ANL studies, which have found that ANL is not related to scores of speech understanding in noise (Nabelek et al., 2004, 2006). Different studies have been reported that spectral smearing resulting from reverberation can adversely affect the intelligibility of speech (Houtgast & Steeneken, 1973; Nabelek, Letowski & Tucker, 1989). RTs approaching 1 second can negatively impact the intelligibility of the speech signal for individuals of all hearing abilities, particularly when background noise is present (Nabelek & Pickett, 1974; Sato, Sato, Morimoto & Ota, 2007). So, the RTs of 1.2 and 2 seconds included in the present study were large enough to impact the intelligibility of the speech signal.

One of the effects of reverberation on an acoustic signal is an overall increase in signal intensity (Houtgast & Steeneken, 1973; Finitzo-Hieber & Tillman, 1978), and hence, a decrease in MCL was hypothesized in reverberant conditions in comparison with MCL in the non-reverberant condition. It was also hypothesized that this anticipated change in MCL would result in a change in ANL. But, Franklin, Thelin, Nabelek and Burchfield (2006) had reported that with every 1 dB increase in the presentation level of the primary discourse, the ANL was decreased only by 0.25 dB. This suggested that with 2dB increase in intensity across the reverberant conditions, a maximum decrease in ANL would be only about 0.5 dB.

The increase in ANL with reverberation in the present study can be attributed to the unfavorable influence of reverberation on the primary talker, which might have interfered with the listeners' willingness to accept background noise. The 0.4 seconds reverberation is not functional enough to impede the primary talker and hence the difference between ANLs for non reverberant stimuli and 0.4 seconds reverberant stimuli is less compared to ANLs for non reverberant stimuli and stimuli with RT of 2 seconds. The absence of significant difference between ANL for RT of 1.2 seconds and that for non reverberant stimuli can be correlated to the BNL that the participants were able to put-up-with. The RT of 1.2 might not have interfered with the primary talker and hence the ANL for RT of 1.2 seconds is not significantly different from that for a non- reverberant primary talker.

Effect of Reverberation on ANL in Participants with Hearing Impairment (Group II)

Descriptive statistics was done to calculate the mean and standard deviation (SD) of MCL, BNL and ANL of individuals with hearing impairment under different reverberant conditions. Table 2 shows the mean and SD of MCL, BNL& ANL of participants of Group II under non reverberant and different reverberant conditions.

Unaided Condition: The unaided ANL varied from 5 to 23 dB with a mean (SD) of 11.80 (6.11) for non - reverberant condition. From Table 2, it can be noticed that in unaided condition, the mean ANL for non reverberant stimulus (ANL2) in individuals with hearing impairment was 11.80 dB. The unaided ANL for the stimulus with RT of 0.4 seconds (ANL2a), 1.2 seconds (ANL2b) and 2 seconds (ANL2c) were 12.87 dB, 18.93 dB and 28.00 dB respectively.

Repeated measure ANOVA was done to find out the within conditions effects of Group II (unaided). Significant difference was noticed with $F(3, 42) = 68.242$, $p < 0.01$. Multivariate ANOVA was done to find out the between conditions effects of Group II (unaided). Significant difference was noticed with $F(3, 12) = 55.038$, $p < 0.01$. In both the cases, Post hoc analysis (Bonferroni) was administered and the result showed significant difference between the conditions at $p < 0.01$ level.

Table 3: Comparison between ANLs of Participants of Group I and unaided ANLs of Participants of Group II

Group comparison	F value	Sig.
ANL1 vs. ANL2	7.215	.012
ANL1a vs. ANL2a	14.235	.001
ANL1b vs. ANL2b	25.098	.000
ANL1c vs. ANL2c	80.275	.000

Significant difference was present between ANLs for non-reverberant stimulus and those for stimulus with RT of 1.2 and 2 seconds. The ANLs for stimulus with RT of 0.4, 1.2 and 2 seconds were significantly different from each other. But ANLs for non- reverberant stimulus were not significantly different from those for stimulus with RT of 0.4 seconds. RTs approaching 1 second can negatively impact the intelligibility of the speech signal for individuals of all hearing abilities, particularly when background noise is present (Nabelek & Pickett, 1974; Sato et al., 2007). So, the RTs of 1.2 and 2 seconds included in the present study were large enough to impact the intelligibility of the speech signal.

Comparison of Unaided ANLs of Participants with Hearing Impairment with the ANLs of Those with Normal Hearing across Different Reverberant Conditions

One-way ANOVA was done to compare the unaided ANLs of participants with hearing impairment with the ANLs of those with normal hearing across different reverberant conditions. Table 3 shows the comparison of ANLs of participants of Group I with unaided ANLs of participants of Group II under non reverberant and different reverberant conditions. From the table, it can be

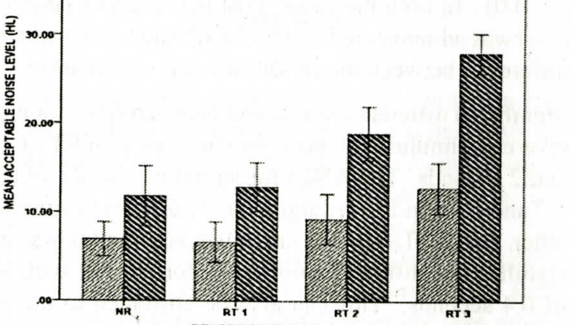

Figure 1: Mean ANL across Different RTs for Group I and Group II (Unaided).

Table 4: Comparison between ANLs of Participants of Group I and aided ANLs of Participants of Group II

Group comparison	F value	Sig.
ANL1 vs. ANL3	6.066	.020
ANL1a vs. ANL3a	1.650	.210
ANL1b vs. ANL3b	11.229	.002
ANL1c vs. ANL3c	17.511	.000

Table 5: Comparison between unaided and aided ANLs of Participants of Group II

Groups	t value	Sig.
ANL2 vs. ANL3	2.306	.037
ANL2a vs. ANL3a	3.043	.009
ANL2b vs. ANL3b	2.283	.039
ANL2c vs. ANL3c	4.899	.000

concluded that ANLs of participants of Group I was significantly different from the unaided ANLs of participants of Group II. Figure 1 represents the mean ANLs of Group I and Group II (unaided) across non- reverberant and different reverberant conditions. As per the results, there was significant difference between the ANLs of Group I and unaided ANLs of Group II in all reverberant conditions. This can be attributed to the fact that individuals with hearing impairment form a highly heterogeneous group, with great variability in speech understanding, particularly in degraded listening conditions such as noise and reverberation (Nabelek & Pickett, 1974; Nabelek & Letowski, 1985). The unaided ANL values are higher compared to those for participants in Group I with maximum difference at RT of 2 seconds, the condition in which the effect of reverberation is more adverse compared to other two conditions of reverberation.

Aided Condition: For the non - reverberated condition, the aided ANL varied from 5 dB to 20 dB with a mean (SD) of 10.73 (04.88). From Table 2, it can be noticed that in aided condition, the mean ANL for non reverberant stimulus (ANL3) was 10.73 dB. The aided ANL for RT of 0.4 seconds (ANL 3a), 1.2 seconds (ANL3b) and 2 seconds (ANL3c) were 8.60dB, 15.87 dB 20.93 dB respectively.

Repeated measure ANOVA was done to find out the within condition effects of Group II (aided). Significant difference was noticed with $F(3, 42) = 36.885$, $p< 0.01$. Also, Multivariate ANOVA was done to find out the between condition effects of Group II (aided). Significant difference was noticed with $F(3, 12) = 23.957$, $p< 0.01$. In both the cases, Post hoc analysis (Bonferroni) was administered and the result showed significant difference between the conditions at $p < 0.01$ level.

Significant difference was found between ANL for non-reverent stimulus and those for stimulus with RT of 1.2 and 2 seconds. The ANLs for stimulus with RT of 0.4, 1.2 and 2 seconds were significantly different from each other. But ANLs for non- reverberant stimulus was not significantly different from ANL for stimuli with RT of 0.4 seconds. This can also be attributed to the adverse influence of reverberation in the presence of background noise which might have reduced the listener's willingness to accept noise while following the words of the primary talker.

Comparison of Aided ANLs of Participants with Hearing Impairment with ANLs of Those with Normal Hearing across Different Reverberant Conditions

One way ANOVA was done to compare the aided ANLs of participants with hearing impairment with the ANLs of those with normal hearing across different reverberant conditions. Table 4 shows the comparison of aided ANLs of participants of Group II with ANLs of Group I participants under non- reverberant and different reverberant conditions. From Table 4, it can be concluded that ANLs of participants of Group I was significantly different from the aided ANLs of participants of Group II.

Figure 2 represents the mean ANLs of Group I and Group II (Aided) across non - reverberant and different reverberant conditions. As per the results, there was significant difference between the ANL of Group I and aided ANLs of Group II in all reverberant conditions except for RT of 0.4 seconds. That is, even with amplification, the performance of Group II participants did not approach the performance of Group I participants. The difference in ANL between Group I and Group II (aided) can be attributed to the lack of acclimatization of the participants of Group II with the hearing aid. Also, the hearing aids were programmed to match the target gain, along with considering the listening needs of

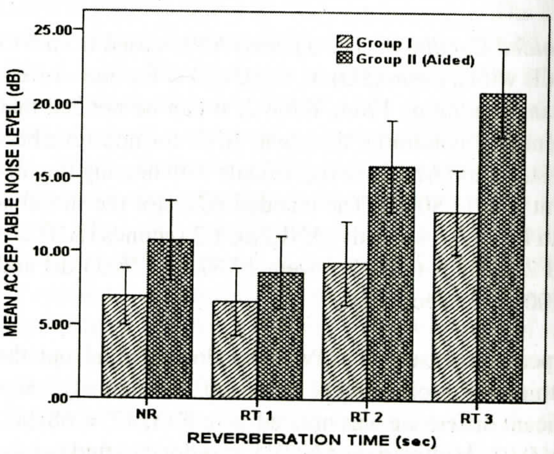

Figure 2: Mean ANL across Different RTs for Group I and Group II (Unaided).

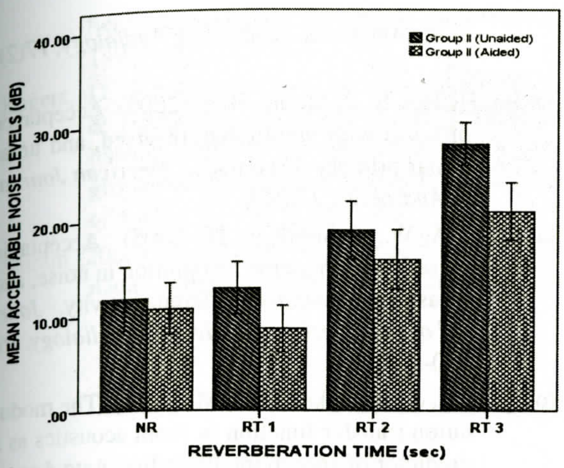

Figure 3: Mean ANL across Different RTs for Group I and Group II (Unaided).

the participants. No other special features for enhancing the listening in presence of reverberation or noise were activated in the hearing aid. This also might have contributed to the difference in ANLs across both the groups.

Comparison of Unaided and Aided ANLs of Participants with Hearing Impairment across Different Reverberant Conditions

Paired sample t test was administered to compare the aided and unaided ANLs of participants with hearing impairment across different reverberant conditions. Table 5 shows the comparison between unaided and aided ANLs of participants of Group II. From Table 5, it can be concluded that the unaided and aided ANLs of participants of Group II was significantly different from each other. Figure 3 represents the mean ANLs of Group II (Unaided & Aided) across non-reverberant and different reverberant conditions. As per the results, there was significant difference observed between the unaided and aided ANLs in all reverberant conditions. The mean difference was maximum for RT of 2 seconds. The aided performance was better even though it is not approaching the performance of participants with normal hearing. This suggests that the willingness to accept noise improved once the amplification was provided. Even though ANL is inherent to the individual (Nabelek et al., 1991), when the amplification is provided, the overall audibility is improved, and that might have contributed to the improvement in aided ANL values compared to unaided condition. But since reverberation is present, the unfavorable influence of reverberation on the willingness to accept background noise affects the individuals with SNHL more adversely than those with normal hearing. Therefore, even though the audibility is improved, the aided performance of individuals with hearing impairment in the presence of reverberation might not approach the ANL values of individuals with normal hearing, even though it is better than the unaided ANLs.

The ANL of all the groups varied between a wide range, which is in support with previous studies (Rogers et al., 2003 & Nabelek et al., 2006). In general, individuals with hearing impairment show great variability in speech understanding, particularly in degraded listening conditions such as noise and reverberation. The adverse effects of reverberation would have interfered with the primary talker used in the present study which would have lead to the increase in MCL as the reverberation time increased. When the primary talker is reverberated, the listener is expected to accept less level of the background noise so as to follow the words of the story at his comfortable level. So, this might have lead to the increase in MCL and decrease in BNL in conditions with reverberation. The 0.4 seconds reverberation is not functional enough to impede the primary talker and hence in cases of Groups I and II, the difference between ANLs for non - reverberant stimuli and 0.4 seconds reverberant stimuli is less compared to ANLs for non reverberant stimuli and stimuli with RT of 1.2 and 2 seconds.

The ANL of all the groups varied between a wide range, which is in support with previous studies (Rogers et al., 2003 & Nabelek et al., 2006). In general, individuals with hearing impairment show great variability in speech understanding, particularly in degraded listening conditions such as noise and reverberation. The adverse effects of reverberation would have interfered with the primary talker used in the present study which would have lead to the increase in MCL as the reverberation time increased. When the primary talker is reverberated, the listener is expected to accept less level of the background noise so as to follow the words of the story at his comfortable level. So, this might have lead to the increase in MCL and decrease in BNL in conditions with reverberation. The 0.4 seconds reverberation is not functional enough to impede the primary talker and hence in cases of normals and hearing impaired, the difference between ANLs for non - reverberant stimuli and 0.4 seconds reverberant stimuli is less compared to ANLs for non reverberant stimuli and stimuli with RT of 1.2 and 2 seconds.

Conclusions

The acceptance of background noise is reliant on the individual person and can unfailingly be tested without hearing aids (i.e., even before aids are recommended and fitted). Thus, the ANL may be beneficial as an indicator of eventual successful hearing-aid use. The ANL measures can be included in the routine audiological test battery as it gives idea regarding the success of hearing aid use and also, it does not take much time to administer (2-3 minutes). ANL values with reverberant primary talker have important application in the field of rehabilitation. The finding that reverberation has negative effect on individual's willingness to accept noise should be considered while designing the classrooms or therapy rooms. This study also emphasize that while programming a hearing aid 'echo stop' feature can be activated which can be used in reverberant environments, so that the willingness to accept noise can be improved.

As people with low ANL values will be successful hearing-aid use, finding an effective strategy to reduce listeners ANLs would increase their chances of benefiting from aural habilitation. Effect of reverberation on ANL needs to be further explored across different degrees of hearing loss, so that optimized and effective fitting can be achieved for individuals with varying degrees of hearing loss. Effect of reverberation on ANL needs to be further probed into in children with hearing sensitivity within normal limits and those with various types and degrees of hearing loss; ANL being an indicator of successful hearing aid usage, it needs to be practiced on a regular basis during the clinical fitting trials.

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