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# Onset of Auditory Deprivation

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**Abstract**

The purpose of this investigation was to study further the assertion that auditory function deteriorates in the unaided ear of individuals with sensorineural hearing loss (SNHL) who receive monaural hearing aid fittings. The word recognition scores (WRSs) of 77 monaurally and 65 binaurally fitted subjects with symmetric bilateral SNHL were examined at 1, 3, and 5 years post hearing aid fitting. The deterioration in auditory function was defined as a significant change in the WRSs for Northwestern University Auditory Test No. 6 (NU-6) materials in the unaided ear of individuals fitted with a monaural hearing aid arrangement. Analyses of the data indicate that 25 percent of the monaurally fitted subjects experienced a significant change in the WRSs of their unaided ears, whereas only 6 percent of the binaurally fitted subjects experienced a significant change in the WRSs of either ear. Auditory function does deteriorate in the unaided ears of individuals with SNHL who receive monaural hearing aid fittings. Moreover, the decline in auditory function of the unaided ear does not result from a decrease in hearing sensitivity.

**Key Words:** Auditory deprivation, binaural amplification, hearing loss, hearing aid effect, monaural amplification, speech recognition, speech perception

**Abbreviations:** NU-6 = Northwestern University Auditory Test No. 6, PTA = pure-tone average, SNHL = sensorineural hearing loss, WRS = word recognition score

More than a decade has passed since Silman et al (1984) reported on the deterioration in auditory function in the unaided ear of individuals with bilateral sensorineural hearing loss (SNHL). In their investigation, the deterioration in auditory function was defined as a progressive decline in the word recognition scores (WRSs) for monosyllabic materials in the unaided ears of individuals fitted with a monaural hearing aid arrangement, an unaided ear effect. A similar deterioration was not found in the group with binaural hearing aid fittings. Further, the decline in the WRS was not associated with a decline in hearing sensitivity. These investigators based their conclusions on the records of male veterans with bilateral symmetric SNHL comparing their initial WRSs to that obtained 4 to 5 years later. In the monaurally aided subject sample, 39 percent of the unfitted ears had a decrease in the WRSs that fell below the 95th percentile critical difference (Thornton and Raffin, 1978), whereas just 4 percent of the binaurally fitted ears demonstrated a similar critical difference in the WRSs. The same investigators confirmed these initial findings of deteriorating auditory function in the unaided ear with another retrospective study of binaurally and monaurally fitted male veterans with binaural SNHL (Gelfand et al, 1987). However, there was no indication in this latter study of the number of subjects whose WRS decline fell below the 95th percentile critical difference.

Recently, Gelfand (1995) provided follow-up data on the 6 (17%) of the 48 monaurally fitted subjects who experienced an unaided ear effect showing that the effect may occur in either the right or the left ear. Further, Silman and colleagues (Silman et al, 1984; Gelfand et al, 1987; Gelfand, 1995) hypothesize that the unaided ear effect results from auditory deprivation. This hypothesis is not, however, universally accepted (Gatehouse, 1989, 1992). Gatehouse hypothesized (1989, 1992) that the aided ear acclimates to receiving speech cues at high sensation levels and thus performs better on the suprathreshold word recognition measure as

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the test materials are presented within the ear's "acclimatized" listening range. In contrast, the unaided ear acclimates to speech cues at low sensation levels and thus performs less well on the suprathreshold word recognition measure because the test's presentation level is above the ear's "acclimatized" listening range. For a comprehensive review of past research, future research needs, auditory system plasticity, and other issues dealing with unaided ear effect, see Eriksholm Workshop on Auditory Deprivation and Acclimation (1996).

Following these initial reports (Silman et al, 1984; Gelfand et al, 1987), other investigators (Hood, 1984; Dieroff and Meiber, 1989; Gatehouse, 1989, 1992; Stubblefield and Nye, 1989; Burkey and Arkis, 1993) studied the unaided ear effect. Hood (1984, 1990) attributed the poorer WRSs in the involved ears of unilateral Meniere's disease subjects compared to the WRSs in the better ears of bilateral Meniere's disease subjects to auditory deprivation, lending support for an auditory deprivation effect. Stubblefield and Nye (1989) and Burkey and Arkis (1993) studied the clinical records of subjects post hearing aid fitting. Analysis of these retrospective data demonstrated a significant decrement in the WRS for the unaided ears and thus provides support for the original observations of Silman and colleagues. Dieroff and Meibner (1989) documented a similar WRS reduction in the unfitted ears of subjects with mixed hearing loss. More recently, investigators illustrated the unaided ear effect with case study reports (Silverman and Silman, 1990; Silman et al, 1992; Boothroyd, 1993; Gelfand, 1995; Hurley, 1993; Silverman and Emmer, 1993). These reports, along with the data of Burkey and Arkis (1993), indicate that the unaided ear effect in some individuals with SNHL can be reversed with binaural amplification. In addition, these case studies show that the unaided ear effect is variable in onset, being as short as 1 to 2 years post monaural hearing aid fitting to as long as 10 years post monaural hearing aid fitting. Gatehouse (1992), however, suggests that the unaided ear effect may take only 12 weeks to occur post monaural hearing aid fitting.

In summary, Silman and colleagues (Silman et al, 1984; Gelfand et al, 1987) and others (Dieroff and Meibner, 1989; Stubblefield and Nye, 1989; Silverman and Silman, 1990; Silman et al, 1992; Burkey and Arkis, 1993; Hurley, 1993; Silverman and Emer, 1993; Gelfand, 1995) provided evidence that in some monaurally fitted individuals with bilateral SNHL, the unfitted ear's WRS decreases over time, whereas the WRSs for the majority of binaurally fitted ears do not demonstrate a similar deterioration within the same time span. However, several questions are still unanswered in spite of subsequent studies 10 years after the Silman et al (1984) paper. The most cogent questions concern the generalization of the previous data (Dieroff and Meibner, 1989; Stubblefield and Nye, 1989; Silverman and Silman, 1990; Silman et al, 1992; Burkey and Arkis, 1993; Hurley, 1993; Silverman and Emmer, 1993; Gelfand, 1995) to the diverse SNHL population because of the limited sample size used in previous studies. Specifically, the questions dealing with data generalization are (1) What is the prevalence of the unaided ear effect; (2) Is the right ear or left ear more prone to the unaided ear effect; (3) Does the amount of hearing loss affect the unaided ear effect; and (4) What is the time course for the onset of the unaided ear effect? These questions are consistent with those raised by the Eriksholm Workshop on Auditory Deprivation and Acclimation (1996).

The purpose of the present investigation was to provide further insight into the unaided ear effect.

## METHOD

### Subjects

Subjects were selected from a record review of a large pool of hearing aid wearers. They consisted of 142 individuals with bilateral symmetric SNHL. By their own choice, 77 subjects were fitted monaurally and 65 subjects were fitted binaurally with amplification. Subjects had an age range of 26 to 76 years with a mean of 58 years. There were 93 males and 49 females. For selection, each subject met the following criteria: (1) average hearing levels of at least 28 dB HL for the octave frequencies of 500 to 2000 Hz ($PTA_1$); (2) a normal tympanogram and contralateral acoustic reflex thresholds within the 95th percentile for the octave frequencies of 500 to 2000 Hz (Silman and Gelfand, 1981); (3) no interaural frequency difference greater than 10 dB HL at two adjoining frequencies for 500 to 4000 Hz; (4) no interaural Northwestern University Auditory Test No. 6 (NU-6) difference greater than 10 percent; (5) an otologic examination prior to the hearing aid fitting; (6) hearing aid fitting within 21 days of the initial hearing evaluation; and (7) reported hearing aid use of at least 8 hours per day. Further, each subject must have had retest evaluations at 1, 3, and 5 years post initial hearing aid fitting.

**Procedure**

The initial and the retest evaluations consisted of (1) pure-tone audiometry, (2) immittance measures, and (3) 50 words per ear of the Auditect™ recording of NU-6 materials presented at 40 dB SL re: the SRT (Wilson et al, 1973). As a matter of policy, any monaurally fitted subject whose WRS fell below the 95th percentile critical difference at any retest was urged to use a binaural hearing fitting for a trial period, whereas any binaurally fitted subject whose WRS feil below the 95th percentile critical difference at any retest was urged to use a monaural fitting for a trial period. A binaural fitting was recommended to determine if it would result in an improvement in the unaided ear's WRS (Silverman and Silman, 1990; Silman et al, 1992; Burkey and Arkis, 1993; Hurley, 1993; Silverman and Emmer, 1993; Gelfand, 1995) and a monaural fitting was recommended for the binaurally involved subjects to determine if it would result in an improvement in the binaural WRS (Jerger et al, 1993). However, not all subjects followed the recommended change in hearing aid fitting. For those subjects who followed the recommendation, each subject elected the hearing aid fitting of their choice, monaural or binaural, at the end of the trial period.

## RESULTS

Figure 1 shows PTA losses for the two hearing aid groups; $PTA_1$ represents the mean hearing threshold level of 500, 1000, and 2000 Hz and $PTA_2$ represents the mean hearing threshold level of 1000, 2000, and 4000 Hz. The monaurally fitted subjects had initial $PTA_1$ values of 36.4 dB for the aided and unaided ears and initial $PTA_2$ values of 47.2 dB and 46.5 dB for the aided and unaided ears, respectively. The binaurally fitted subjects had initial $PTA_1$ values of 35.3 dB and 37.6 dB for the right and left ears, respectively, and initial $PTA_2$ values of 47.0 dB and 47.8 dB for the right and left ears, respectively. The average 2.2 dB change in $PTA_1$ and $PTA_2$ between the initial and final retest was significant for both the aided ($t = 7.05$, $p < .001$; $t = 7.77$, $p < .001$) and unaided ears ($t = 6.58$, $p < .001$; $t = 7.23$, $p < .001$) of the monaurally fitted group. Likewise, the average 1.5 dB change in $PTA_1$ and the average 2.2 dB change in $PTA_2$ between the initial and final retest was significant for both the right ($t = 4.17$, $p < .001$; $t = 5.74$, $p < .001$) and left ears ($t = 4.11$, $p < .001$; $t = 5.74$, $p < .001$) of the binaurally fitted group. Whereas the analyses indicate that the PTA changes were significant, the magnitude of the changes, 1.5 to 2.6 dB, were not clinically meaningful and were the same for both the monaurally and binaurally fitted groups.

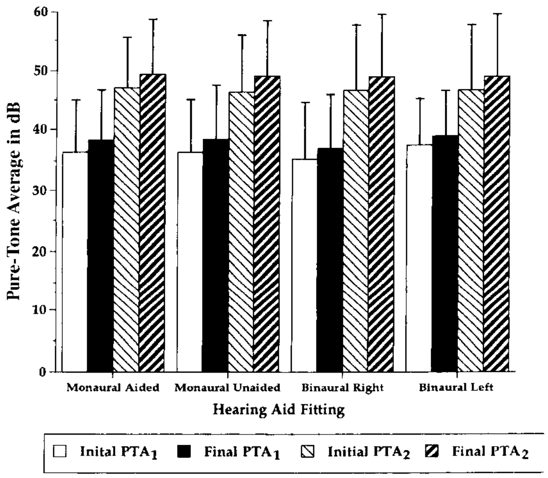


**Figure 1** Mean pure-tone average (PTA) and standard deviations (±1 SD) for the unaided and aided ears of the monaural group and the aided right and left ears of the binaural group at the initial testing. $PTA_1$ is the mean of the hearing threshold levels at 500, 1000, and 2000 Hz and $PTA_2$ is the mean of the hearing threshold levels at 1000, 2000, and 4000 Hz.

The data comparing the initial and subsequent retest WRSs are plotted in the same manner as Silman et al (1984). Figure 2 illustrates the initial and retest data with respect to the upper and lower 95th percentile critical difference. The initial and retest WRSs exceeding the 95th percentile critical difference limits have data points falling outside the jagged ellipse and, as such, are significantly different. Figure 2 displays the number of monaurally fitted subjects whose retest WRSs fell below the 95th percentile critical difference for the 3 retest years. At 1 year post fitting (Fig. 2A), only 1 (1%) of the 77 monaural unaided ears fell below the 95th percentile when the WRSs for the initial test were compared to the WRSs on the retest. At 3 years post fitting (Fig. 2C), 5 (6%) of the 76 monaural unaided ears fell below the 95th percentile when their WRSs for the initial test were compared to their WRSs on the retest. At the final retest, 14 (20%) of the 71 monaural unaided ears fell below the 95th percentile when their WRSs for the initial test were compared to their WRSs on the retest. Of the 20 (26%) unfitted ears with WRSs that fell below the 95th percentile

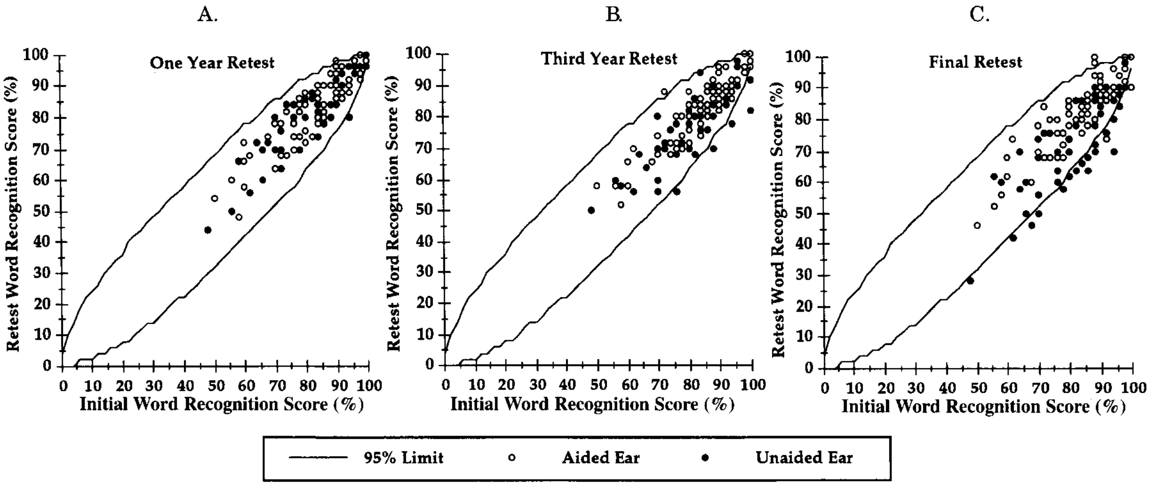


**Figure 2** Plots of the initial and two subsequent years of retest word recognition scores (WRSs) of the aided and unaided ears of the monaurally fitted subjects. The jagged ellipse represent the upper and lower limits of the 95th percentile critical difference for the reliability of WRS. *A*, plot of the initial retest WRS at 1 year post hearing aid fitting; *B*, plot of the initial and retest WRS at 3 years post hearing aid fitting; *C*, plot of the initial and retest WRS at 5 years post hearing aid fitting.

at a retest, 19 were left ears whereas 1 was a right ear. The dominance of the left ear was biased by the fact that 90 percent of the subjects were fitted in the right ear. The two aided ears with retest WRSs below the 95th percentile at the final retest were both left ears.

Figure 3 displays the initial and retest data for the binaurally fitted subjects with respect to the upper and lower 95th percentile critical difference. The initial and retest WRSs exceeding the 95th percentile critical difference limits have data points falling outside the zigzag diagonals and, as such, are significantly different. Figure 3 displays the number of binaurally fitted subjects whose initial and retest WRSs fell below the 95th percentile critical difference for the four retests. For the 1 year and 3 year post fitting retests (Fig. 3A and 3B), none of the binaurally fitted subjects' ear fell below the 95th percentile when their initial WRSs were compared to their WRSs on the retest. On the final retest (Fig. 3C), 4 (6%) ears of the 65 binaurally aided subjects fell below the 95th percentile when their initial WRSs were

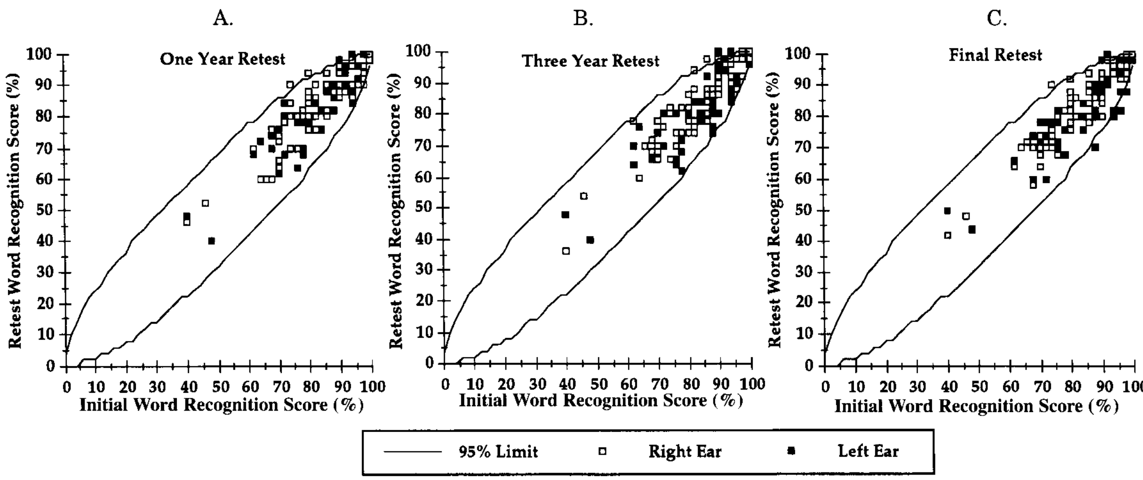


**Figure 3** Plot of the initial and two subsequent years of retest word recognition scores (WRSs) of the right and left ears of the binaurally fitted subjects. The jagged ellipse represent the upper and lower limits of the 95th percentile critical difference for the reliability of WRS. *A*, plot of the initial and retest WRS at 1 year post hearing aid fitting; *B*, plot of the initial and retest WRS at 3 years post hearing aid fitting; *C*, plot of the initial and retest WRS at 5 years post hearing aid fitting.

compared to their WRSs on the retest. Closer inspection of the binaural data reveals that the four ears with WRSs that were below the 95th percentile critical difference at the final retest were left ears.

The monaurally fitted subjects with significant WRS decline had mean $PTA_1$ and $PTA_2$ values of 46.2 dB and 58.1 dB, respectively, whereas the monaurally fitted subjects without significant WRS decline had mean $PTA_1$ and $PTA_2$ values of 35.1 dB and 46.0 dB, respectively. These differences in average hearing loss between the two groups were significant for both $PTA_1$ ($t = 5.88$, $p < .001$) and $PTA_2$ ($t = 5.05$, $p < .001$). Further, a comparison of the initial PTAs and the PTAs at the time the WRS fell below the 95th percentile critical difference showed that the average $PTA_1$ change was 2.6 dB and the average $PTA_2$ change was 2.9 dB. Whereas the PTA changes were significant ($t = 4.44$, $p < .001$; $t = 4.54$, $p < .001$), the magnitude of changes was small and was comparable to those of subjects who did not demonstrate the unaided ear effect.

## DISCUSSION

The finding of a reduction in WRS performance for the monaural unaided ears is consistent with the report of Silman et al (1984). The total number of individuals who experienced the unaided ear effect differs, however, between the studies. Silman et al (1984) reported 39 percent, whereas the present investigation reports 25 percent. Both studies, Silman et al (1984) and the present investigation, report similar data for binaurally fitted subjects (4% and 6%, respectively). Although the difference in the prevalence of the unaided ear effect between the studies may be confounded by differences in subject sample size and composition, a more likely reason is the difference in degree of hearing loss of the subjects used in Silman et al (1984) and the present investigation. In the Silman et al (1984) study, $PTA_1$ and $PTA_2$ values were approximately 50 dB and 60 dB, respectively. In the present investigation, however, $PTA_1$ and $PTA_2$ values were approximately 36 dB and 46 dB, respectively. The 15 dB greater average hearing loss in the Silman et al (1984) subjects may account for the greater prevalence of the unaided ear effect. The link between degree of hearing loss and the unaided ear effect is supported in the present investigation by the fact that subjects with significant WRS decline had average $PTA_1$ (46 dB) and $PTA_2$ (58 dB) values closer to the $PTA_1$ and $PTA_2$ values of the Silman et al (1984) subjects than their cohorts without WRS decline.

Silverman and Silman (1990) and Silman et al (1992) indicated that the unaided ear effect can occur as quickly as 2 years after the original monaural hearing aid fitting. The average time span was 4 years for the significant WRS change to occur (Silman et al, 1984; Gelfand et al, 1987). The present results suggest that the unaided ear effect can occur as quickly as 1 year post monaural hearing aid fitting, although the prevalence would be small (1%). If one assumes that once the unaided ear effect has occurred the affected ear would continue to show deterioration in auditory function, the prevalence at 3 years post fitting would be 8 percent, and the prevalence at 5 years post fitting would be 26 percent. The above is based on the definition of the unaided effect as a significant reduction in the WRS for monosyllabic words, materials that are known to be relatively insensitive to subtle changes in auditory function. Interestingly, Gatehouse (1992) demonstrated a decrease in the auditory function of the unfitted ear only 3 months after the monaural fitting using speech-in-noise materials, suggesting that the unaided ear effect could be detected sooner if a more sensitive test paradigm, such as speech-in-noise materials and/or high-frequency weighted speech materials, was used.

It is of interest that the ear displaying the deteriorating auditory function was predominantly the left ear for both the monaurally fitted and binaurally fitted subjects. Not only did 31 percent of the monaurally right ear fitted group develop an unaided ear effect, as opposed to 21 percent of the monaurally left ear fitted group, but the two cases in which the aided ears' WRS fell below the 95th percentile critical difference at the final retest were left ears. Further, the 6 percent of the binaurally fitted group who had WRS fall below the 95th percentile critical difference were left ears. Although not a significant effect in this investigation, the left ear of some individuals with bilateral SNHL may be more susceptible to deterioration in auditory function over time (Jerger et al, 1994).

In summary, the unaided ear effect, a deterioration in auditory function over a 5-year time span, was reflected in the WRSs in the unaided ear of some individuals with monaural hearing aid fittings. This decline in the WRS was not accounted for by a decline in hearing sensitivity.

The precipitating factors for the unaided ear effect are an unaided ear $PTA_1 \geq 46$ dB and a $PTA_2 \geq 58$ dB, leading to the conclusion that the amount of hearing loss plays a major role in the onset of the unaided ear effect through protracted auditory deprivation.

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