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Auditory Deprivation in Adults with Asymmetric, Sensorineural Hearing Impairment

Carol A. Silverman*†‡§**
Shlomo Silman§**††
Michele B. Emmer§††
Janet R. Schoepflin‡‡
John J. Lutolf §§***

Abstract

The purpose of this investigation was to prospectively examine performance on the pure-tone air-conduction threshold, speech-recognition threshold, and suprathreshold word-recognition tests over time in 21 monaurally aided (experimental group) and 28 unaided adults (control group) with asymmetric, sensorineural hearing impairment.

The results revealed significant declines on the mean suprathreshold word-recognition scores over time at one and two years post-baseline for the worse ears of the control participants; no declines occurred in the worse ears of the experimental participants or in the better ears of either group. A slight, significant increase in the pure-tone average occurred for the better ears of both groups. The findings are consistent with the presence of an auditory deprivation effect on suprathreshold word-recognition ability in the control group, suggesting that lack of amplification leads to decline in word-recognition performance over time in the worse ears of adults with asymmetric sensorineural hearing impairment.

Key Words: Amplification, asymmetric hearing loss, auditory deprivation, hearing aids, speech recognition, unilateral hearing loss, word recognition

Abbreviations: SRT = speech-recognition threshold; WRS = word-recognition score

Sumario

El propósito de esta investigación fue el examen prospectivo del desempeño ante umbrales tonales puros por conducción aérea, en umbrales ante reconocimiento del lenguaje y pruebas de reconocimiento supra-umbral de palabras, de 21 adultos con amplificación monoaural (grupo experimental) y 28 adultos sin amplificación (grupo control), con una hipoacusia sensorineural asimétrica.

Los resultados revelaron deterioro significativo en el tiempo de los puntajes medios supra-umbrales de reconocimiento de palabras, uno y dos años después de la medición basal, en el oído peor de los participantes control; no

*Communication Sciences Program, Hunter College, CUNY; †Department of Otolaryngology—Head and Neck Surgery, New York Medical College; ‡Departments of Otolaryngology—Head and Neck Surgery and Communication Sciences, New York Eye and Ear Infirmary; §Au.D. Program in Audiology, Graduate Center, CUNY; **Ph.D. Program in Speech and Hearing Sciences, Graduate Center, CUNY; ††Department of Speech Communication Arts and Sciences and Center for Auditory Research, Brooklyn College, CUNY; ‡‡Department of Communication Sciences and Disorders, Adelphi University; §§Department of Speech, Communication Sciences and Theater, St. John's University; ***Audiology and Speech Pathology Service, Department of Veterans Affairs, East Orange, NJ

Carol A. Silverman, Ph.D., M.P.H., Communication Sciences Program, Hunter College, CUNY, 425 East 25th St., New York, NY 10010; Phone: 212-481-4467; E-mail: profaud@nyc.rr.com

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ocurrió deterioro en los oídos peores del grupo experimental, o en el oído mejor de ambos grupos. Un incremento leve pero significativo en el promedio tonal puro ocurrió para los oídos mejores en ambos grupos. Los resultados son consistentes con la presencia de un efecto de deprivación auditiva en la capacidad de reconocimiento supra-umbral de palabras en el grupo control, sugiriendo que la falta de amplificación lleva a un deterioro en el tiempo del desempeño en reconocimiento de palabras, en los oídos peores de adultos con hipoacusia sensorineurales asimétricas.

Palabras Clave: Amplificación, hipoacusia asimétrica, deprivación auditiva, auxiliares auditivos, reconocimiento del lenguaje, hipoacusia unilateral, reconocimiento de palabras

Abreviaturas: SRT = umbral de reconocimiento del lenguaje; WRS = puntaje de reconocimiento de palabras

The initial investigation of auditory deprivation associated with lack of amplification in adults with hearing impairment was performed by Silman et al (1984). Their retrospective study was conducted on 44 monaurally aided and 23 binaurally aided veterans with bilateral, symmetric, sensorineural hearing impairment who were seen at the time of hearing-aid fitting and four to five years postfitting. The results revealed the absence of significant changes from test to retest in the unaided and aided ears of the monaurally aided group or in the right or left ears of the binaurally fitted group with respect to the mean pure-tone thresholds or speech-recognition thresholds (SRTs). A significant decline (18.5%) from test to retest, however, occurred in the mean suprathreshold W-22 word-recognition score (WRS) for the unaided ears of the monaural fitted group at the retest. This decline contrasted with the lack of significant change in the mean WRS over that period for the aided ears of the monaural group (2.6% decline) and for the right (1.9% decline) and for the left (1.6% decline) ears of the binaurally fitted adults. Based on the Thornton and Raffin (1978) and Raffin and Schafer (1980) 95th percentile critical difference limits that were constructed using the binomial model for variability in suprathreshold WRSs, Silman et al (1984) observed significant declines over time in 39% of the unaided ears of the monaural group in contrast with 4% of the aided ears of the monaural group, 4% of the aided right ears of the binaural group, and 4% of the aided left ears of the binaural group. They concluded that the decrement over time on the WRSs for the unaided but not aided ears is consistent with adult-onset auditory deprivation whereby prolonged lack of amplification in the unaided ear can lead to an observed decline on suprathreshold word-recognition performance.

The auditory deprivation effect on the WRSs of adults that was reported by Silman et al (1984) has been substantiated by numerous investigators (Gelfand et al, 1987; Dieroff and Meiβner, 1989, 1994; Gatehouse, 1989; Silverman, 1989; Stubblefield and Nye, 1989; Emmer, 1990; Silverman and Silman, 1990; Silman et al, 1992, 1993; Burkey and Arkis, 1993; Dieroff, 1993; Gelfand, 1995; Hurley, 1993, 1998, 1999; Sanguy and Olivier, 1996). The finding of an absence of an auditory deprivation effect on the pure-tone hearing threshold levels and SRTs has been substantiated by several investigators (Gelfand et al, 1987; Stubblefield and Nye, 1989; Burkey and Arkis, 1993; Hurley, 1999). Auditory deprivation effects associated with lack of amplification have been observed in children as well as adults (Boothroyd, 1993; Gelfand and Silman, 1993; Hattori, 1993). They also have been observed for the P300 in the unaided ears of monaurally fitted children (Hutchinson and McGill, 1997). Silman et al (1998) described the telephone ear effect whereby significantly poorer WRSs were obtained in the ear not habitually used for the telephone than in the ear habitually used for the telephone; they attributed the effect to auditory deprivation in the nontelephone ear. The consensus statement of the 1995 Ericksholm Consensus Conference on Auditory Deprivation and Acclimatization (a) concluded that the auditory deprivation effect associated with monaural amplification of persons with bilateral hearing impairment is statistically significant; and (b) recommended binaural fittings for bilateral moderate or worse hearing impairment (Arlinger et al, 1996).

Hood's (1984, 1990) findings for unaided persons with unilateral and bilateral sensorineural hearing impairment support the concept of auditory deprivation in relation to suprathreshold speech-recognition ability. He compared the articulation functions for monosyllabic phonemically balanced words for the better ears of 12 subjects with bilateral sensorineural hearing impairment due to Meniere's disease with those for the poorer ears of 23 matched (within ±5 dB of the four-frequency pure-tone average) subjects with unilateral sensorineural hearing impairment due to Meniere's disease. Inspection of these articulation functions revealed that the WRSs for the impaired ears of the unilateral subjects were lower, often markedly lower, than those for the matched ears of the bilateral subjects. Also, the frequency of occurrence and degree of rollover of the articulation functions were increased in the affected ears of the unilateral subjects as compared with the better ears of the bilateral subjects. Hood (1984, 1990) also compared the articulation functions of the better ears with those of the poorer ears from eight subjects with slightly asymmetric, bilateral sensorineural hearing impairment due to Meniere's disease; inspection of these audiograms reveals that the average interaural difference in four-frequency pure-tone average was approximately 18 dB. Perusal of those articulation functions reveals that the suprathreshold WRSs at all intensities for the poorer ear were markedly poorer than those for the better ear for all of the subjects.

Hood (1984, 1990) concluded that his findings show that the subjects with unilateral sensorineural hearing impairment or bilateral, asymmetric sensorineural hearing impairment make dominant use of the better ear to the neglect of the poorer ear, even when interaural pure-tone threshold differences are slight. He drew a "clear parallel" (1990, p. 8) between his findings and those of Silman et al (1984). Thus, Hood's findings suggest that slight pure-tone asymmetry can result in auditory deprivation effects as evidenced by marked asymmetry in suprathreshold WRSs that reflect substantially poorer speech recognition in the slightly poorer as contrasted with the slightly better ear; such a finding resembles the auditory deprivation effect from monaural amplification of a person with bilateral, symmetric sensorineural hearing impairment, as manifested by a decrement in the WRSs in the unaided ear. Both asymmetric sensorineural hearing impairment and monaural amplification of bilateral, symmetric sensorineural hearing impairment yield asymmetry in auditory stimulation leading to decrements in the WRS for the worse ear (in persons with asymmetric hearing impairment) or for the unaided ear (of monaurally fitted persons with bilateral, symmetric hearing impairment).

Moore and Glasberg (1987) and Glasberg and Moore (1989) prospectively investigated the SRT in quiet and in noise in nine participants with unilateral sensorineural hearing impairment and six participants with bilateral sensorineural hearing impairment. For the SRT in noise, the S/N ratio associated with 50% recognition performance was measured. The pure-tone air-conduction thresholds of the impaired ears of the subjects with unilateral sensorineural hearing impairment were slightly greater than those of the impaired ears of the subjects with bilateral sensorineural hearing impairment. The mean S/N ratio for speech presented in 75 dB SPL of noise was 7.1 dB for the impaired ears of the unilateral group versus 1.3 dB for the bilateral group, suggesting worse speech-recognition performance for the unilateral as compared with the bilateral group; the slight pure-tone differences between groups were unlikely to account for the large between-group differences in S/N ratio. Glasberg and Moore (1990, personal communication) reanalyzed their 1987 and 1989 data and also found poorer speech-recognition performance in the affected ears of the unilateral subjects than in the unaided as well as the aided ears of the bilateral subjects. Thus, speech-recognition performance in the unilateral group was poorer than that for the bilateral group, regardless of amplification status in the latter group.

Although numerous studies have been published on auditory deprivation associated with monaural amplification of adults with bilateral, symmetric hearing impairment, only one study has been published on auditory deprivation association with lack of amplification in adults with asymmetric sensorineural hearing impairment, and that study presents retrospective case studies (Silverman and Emmer, 1993). No published prospective studies exist on auditory deprivation in unaided persons with asymmetric sensorineural hearing impairment.

Silverman and Emmer (1993) investigated whether auditory deprivation effects were present in the poorer ears of unaided adults with asymmetric sensorineural hearing impairment. They retrospectively reviewed the records of 15 male adults with bilateral asymmetric sensorineural hearing impairment and one adult with unilateral hearing impairment. Of the 16 adults, eight were monaurally fitted, and eight were unaided. The retest test was performed at two to 13 years post–initial test. The results of t-tests for repeated measures revealed a significant difference between the initial and retest WRSs only for the poorer ears of the unaided subjects, with the mean retest WRS significantly poorer than the mean initial test WRS. This finding is consistent with the presence of auditory deprivation in the poorer ears from longstanding asymmetric hearing impairment. In the aided subjects, a slight, although nonsignificant, improvement was seen in the mean WRS for the poorer ear, possibly consistent with recovery from auditory deprivation associated with amplification of a formerly unaided ear. The results also revealed that in a substantial proportion (80%) of the poorer ears of the unaided group, in contrast with only 20% of the better ears of the unaided group, the retest WRS fell below the 95th percentile critical difference limit. The auditory deprivation effect was more marked for the unaided, poorer ears of persons with asymmetric sensorineural hearing impairment than for the unaided ears of monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment.

Thus, the limited available retrospective research on adults with unilateral or asymmetric sensorineural hearing impairment suggests that auditory deprivation effects may be more striking in this population than in the population of monaurally fitted persons with bilateral, symmetric sensorineural hearing impairment (Silverman and Emmer, 1993). The results of auditory deprivation studies on adults with asymmetric sensorineural hearing impairment have implications for hearing-aid fitting practices in persons with asymmetric sensorineural hearing impairment.

Therefore, the purpose of this investigation was to prospectively evaluate performance on the pure-tone air-conduction thresholds, SRT, and suprathreshold W-22 word-recognition tests over time (one and two years from baseline) in aided and unaided adults with asymmetric sensorineural hearing impairment. The specific question addressed, in relation to the better and worse ears of aided and unaided adults with asymmetric sensorineural hearing impairment, was as follows: Do changes over time occur on these measures? If so, do significant differences in performance over time exist between groups?

METHOD

Participants

Participants included adults with asymmetric sensorineural hearing impairment due to nonfluctuant cochlear etiology. Approximately 55% of the participants were veterans. All participants were native speakers of English. The participants fitted with monaural amplification comprised the experimental group, and the unaided participants comprised the control group

All participants met the following criteria for study inclusion: (a) acoustic-immittance test results consistent with the absence of conductive pathology (peak-compensated static-acoustic admittance ≥.35 mmho and ≤1.35 mmho and tympanometric peak pressure >-50 daPa); (b) otolaryngologic findings consistent with the absence of conductive and retrocochlear pathology; (c) negative history of neurologic disorders; (d) reported onset of hearing impairment in adulthood; (e) air-bone gaps not exceeding 10 dB at frequencies between 250 and 4000

Hz; (f) nonfluctuant hearing impairment; (g) negative history of hearing-aid use; (h) ≥20 dB asymmetry in the pure-tone air-conduction threshold between the worse and better ears for at least three frequencies; (i) pure-tone air-conduction threshold for the worse ear that equals or exceeds that for the better ear at all frequencies between 250 and 8000 Hz, inclusive; (j) measurable speech-recognition threshold (SRT) within audiometric limits; and (k) >0% score for monosyllabic W-22 PB words presented at 40 dB SL re: SRT.

The participants were recruited from the Audiology and Speech Pathology Services of the Veterans Administration Medical Centers in East Orange, NJ; Bricktown, NJ; Brooklyn, NY; and from the Speech and Hearing Centers of Brooklyn College, CUNY, Brooklyn, NY; Hunter College, CUNY, New York, NY; and Kingsbrook Jewish Medical Center, Brooklyn, NY. For both the experimental aided and control unaided groups, approximately 40% of the persons referred met the study criteria. Persons meeting all criteria for study inclusion were entered into the investigation if they consented to participate.

At year 0 (baseline), 28 control unaided participants (24 males and 4 females) and 21 experimental aided participants (18 males and 3 females) were enrolled in the study. The mean age was 54.4 years (SD = 15.5 years, range = 22–77 years) for the unaided group, and 55.7 years (SD = 15.1 years, range = 28–78 years) for the aided group. The worse ear was the left ear in 14 of the 21 aided participants and in 14 of the 28 unaided participants. The etiology of the hearing impairment was noise-induced hearing loss in 12 of the aided subjects and 15 of the unaided subjects; it was acoustic trauma in the remainder of each group.

Procedures

Measures annually administered to each ear of each participant included the following: (a) pure-tone air-conduction testing at 250, 500, 1000, 2000, 4000, and 8000 Hz using the Carhart-Jerger Modified Hughson-Westlake (Carhart and Jerger, 1959) threshold procedure; (b) pure-tone bone-conduction testing at 250, 500, 1000, 2000, and 4000 Hz using the Carhart-Jerger Modified Hughson-Westlake (Carhart and Jerger, 1959) threshold procedure; (c) speech-recognition threshold (SRT) testing (Auditec of St. Louis W-1 cassette recording, male voice) in quiet using the Chaiklin and Ventry (1964) procedure; (d) suprathreshold word-recognition testing with CID W-22 PB monosyllabic words (Auditec of St. Louis cassette recording, male voice) at 40 dB SL re: SRT (or lower sensation levels if audiometric limits or tolerance problems precluded testing at 40 dB SL) (50-word list); and (f) admittance-pressure function, which yields the tympanometric peak pressure and peak-compensated static-acoustic admittance. The order of testing was as follows: (a) routine audiologic tests (acoustic-admittance pressure function, air- and bone-conduction assessment, SRT in quiet); (b) W-22 tests.

The referring centers fitted the poorer hearing ear of each experimental participant with monaural amplification. The initial assessments for these participants were performed within one week of the hearing-aid fitting. All participants were tested at yearly intervals over a two-year period (year 0, initial test; year 1, retest; and year 2, retest).

Statistical Analyses

All statistical analyses were performed using STATA Special Edition version 8.2 (StataCorp, College Station, Texas). For each subject, difference scores for each outcome measure were obtained: (a) score at year 1 minus score at year 0; and (b) score at year 2 minus score at year 0. The interaural difference in pure-tone air-conduction threshold was obtained by subtracting the air-conduction threshold for the better ear from that for the poorer each, at each frequency. An alpha level of .05 was used for all statistical tests.

In order to select appropriate statistical tests, skewness and variance on each measure were examined for each group (experimental aided vs. control unaided) at each time point (year = 0, 1, and 2).

Power (1-β) is the probability that if the two populations differ, the two samples will show a significant difference. For 80% power, at 95% confidence, the sample size needed to detect a difference between the means (18.5% for the control unaided group vs. 2.6% for the experimental aided group, assuming a standard deviation of 19.6% for the former group and 19.2% for the latter group) is 20 for each group. These assumptions for the means are based on the findings of Silman et al (1984) on adults with bilateral, symmetrical hearing impairment.

RESULTS

Interaural Difference in Pure-Tone Air-Conduction Thresholds

Significant skewness in the interaural difference in pure-tone air-conduction thresholds was present at 250 and 500 Hz for both groups and at 1000 Hz and for the four-frequency pure-tone average (PTA) for the control unaided group at baseline (year = 0). Therefore, the interquartile ranges were plotted for each interaural difference at year = 0 for the control unaided group (see Fig. 1) and for the experimental aided group (see Fig. 2). The box and whisker plots in Figures 1 and 2 show that the median interaural asymmetry is greatest at the high frequencies (2000–4000 Hz) at the baseline test (year = 0). The median interaural difference values range from 12.5 dB at 250 Hz to 45 dB at 2000 Hz for the control unaided group and from 15 dB at 250 Hz to 45 dB at 2000 and 4000 Hz for the experimental aided group.

PTA

The results of parametric t-tests (based on the assumption of equal variances between groups) on the PTA difference scores at both years were nonsignificant for both ears of both groups, so the null hypothesis of no significant difference in the mean PTA difference score between groups is not rejected at either year 1 (df = 47; t = -.44 for the worse ears and t = -1.24 for the better ears) or year 2 (df = 33; t = -.32 for the worse ears and t = .94 for the better ears). The mean increase in PTA for the better ear from year 0 to year 2 was only 3.3 dB in the experimental aided group and 2.1 dB in the control unaided group. In the worse ear, the mean increase was only .79 dB for the experimental aided group and 1.4 dB for the control unaided group.

The assumption for using confidence intervals is that the variable is distributed normally. The PTA difference scores for the worse and better ears at years 1 and 2 were unskewed. Inspection of the 95% confidence intervals for the mean difference between groups in the PTA difference score for the worse and better ears shows that they contain 0 at years 1 and 2 (see Tables 1 and 2), consistent with the absence of significant differences between groups in the mean PTA difference score for both ears at both years.

The confidence intervals for each group

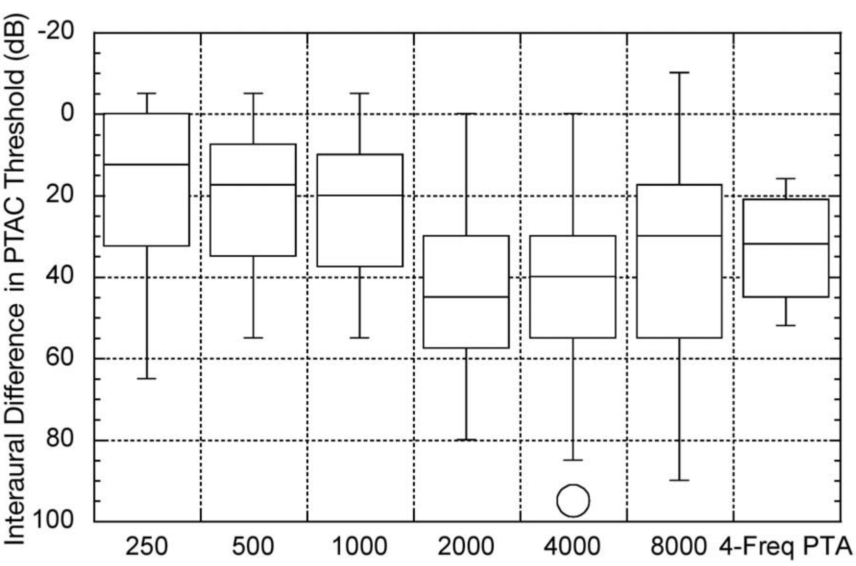

Figure 1. The box plots show the interquartile range (Q1 to Q3) for the interaural difference in pure-tone air-conduction (PTAC) threshold across the frequency range and four-frequency PTA for the control unaided group at the initial test (year 0). The horizontal line inside the box represents the median interaural difference in pure-tone air-conduction threshold. The whiskers represent the range from +1.5X the IQ to -1.5X the IQ. The circle represents an outlier.

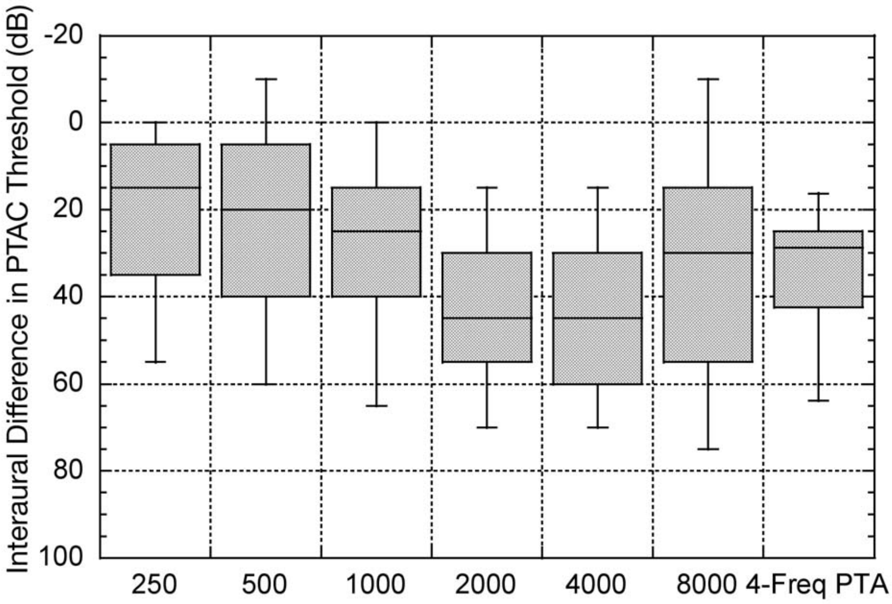

Figure 2. The box plots show the interquartile range (Q1 to Q3) for the interaural difference in pure-tone air-conduction (PTAC) threshold across the frequency range and four-frequency PTA for the experimental aided group at the initial test (year 0). The horizontal line inside the box represents the median interaural difference in pure-tone air-conduction threshold. The whiskers represent the range from +1.5X the IQ to -1.5X the IQ.

also were examined at both years to determine whether a within-group change occurred on the PTA between years 0 and 1 or between years 0 and 2. The results revealed that the confidence intervals for the PTA difference score for the worse ear contained 0 at years 1 and 2 for both groups, suggesting the absence of significant changes in the mean PTA for the worse ear over time for both groups. On the other hand, for the PTA

Table 1. Means, Standard Errors, Standard Deviations, and 95% Confidence Intervals for the PTA Difference Score for the Worse Ears at Years 1 and 2

Group	N	Mean	SE	SD	95% Confidence Interval
Year 1					
Experimental	21	0	1.10	5.03	(-2.2896, 2.2896)
Control	28	.57	.78	4.12	(-1.0271, 2.1700)
Difference		-.57	1.31		(-3.2027, 2.0598)
Year 2					
Experimental	19	.79	1.39	6.08	(-2.1405, 3.7194)
Control	16	1.38	1.15	4.59	(-1.0698, 3.8198)
Difference		-.59	1.85		(-4.3492, 3.1782)

Table 2. Means, Standard Errors, Standard Deviations, and 95% Confidence Intervals for the PTA Difference Score for the Better Ears at Years 1 and 2

Group	N	Mean	SE	SD	95% Confidence Interval
Year 1					
Experimental	21	-.38	.53	2.44	(-1.4911, .7292)
Control	28	.79	.71	3.76	(-.6703, 2.2418)
Difference		-1.17	.94		(-3.0602, .7269)
Year 2					
Experimental	19	3.32	.92	3.99	(1.3942, 5.2374)
Control	16	2.13	.85	3.38	(.3219, 3.9281)
Difference		1.19	1.26		(-1.3806, 3.7622)

difference score for the better ear, the results revealed that the confidence intervals did not contain 0 at year 2 (although they did at year 1), suggesting a significant change in the mean PTA for the better ear from year 0 to year 2 (but not from year 0 to year 1) for both groups. The finding that the confidence interval for the mean difference between groups in PTA difference score for the better ear at year 2 contained 0 in conjunction with the finding that the confidence intervals for the mean PTA difference scores for the better ears of both groups did not contain 0 suggests that the change in mean PTA for the better ear that occurred from year 0 to year 2 was essentially equal for both groups.

SRT

The results of the parametric *t*-test (based on the assumption of equal variances between groups) on the mean SRT difference score for the better ear between groups were nonsignificant at years 1 (df = 47, t = -.5733) and 2 (df = 33, t = -.3804). Therefore, any change in SRT that occurred for the better ear was similar at years 1 and 2 for both groups. The mean change in SRT from year 0 to year 2 in the better ear was only 1.1 dB for the experimental aided group and 1.6 dB for the control unaided group (see Table 3).

The results of the nonparametric Wilcoxon rank-sum (Mann-Whitney) test on the median SRT difference score for the worse ear are nonsignificant at years 1 (test statistic z = .568) and 2 (test statistic z = -.680). Thus, the changes in median SRT for the worse ear from year 0 to year 1 and from year 0 to year 2 were similar for the experimental aided and control unaided groups.

The SRT difference scores for the better ears at years 1 and 2 were distributed normally for both groups, so they meet the assumption for the use of confidence intervals. The confidence intervals for the SRT difference score are shown for the better ear in Table 3.

Inspection of the 95% confidence interval for the difference between groups in the mean SRT difference score for the better ear shows that it does contain 0 at years 1 and 2, suggesting no significant difference between groups in the mean SRT difference score at either year. The confidence intervals for the SRT difference score for the better ear contained 0 at years 1 and 2 for both groups, consistent with the absence of a significant change in mean SRT of the better

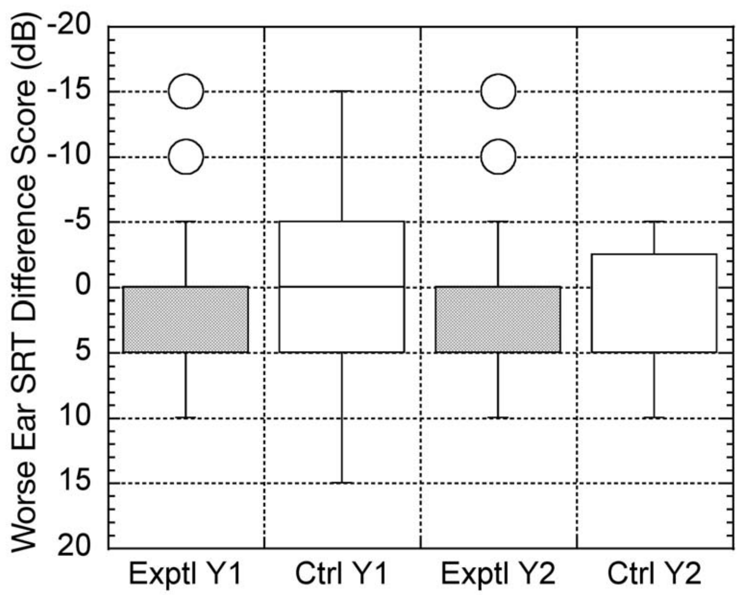

Figure 3. The box and whisker plots show the interquartile range (Q1 to Q3) for the SRT difference score at years 1 and 2 for the worse ear for both groups (Exptl = experimental aided group; Ctrl = control unaided group). The horizontal line inside the box represents the median SRT difference score for the worse ear. For the experimental aided group at years 1 and 2 and control unaided group at year 2, the horizontal line, representing the median SRT difference score for the worse ear cannot be seen because the 50% value equals the 75% value in these cases. The whiskers represent the range from +1.5X the IQ to -1.5X the IQ. The circles represent the outliers.

Table 3. Means, Standard Errors, Standard Deviations (SDs), and 95% Confidence Intervals (95% CI) for the SRT Difference Score for the Better Ears at Years 1 and 2

Group	N	Mean	SE	SD	95% Confidence Interval
Year 1					
Experimental	21	-.48	1.03	4.72	(-2.6239, 1.6715)
Control	28	.36	.99	5.26	(-1.6817, 2.3959)
Difference		-.83	1.45		(-3.7576, 2.0909)
Year 2					
Experimental	19	1.06	.98	4.28	(-1.0078, 3.1131)
Control	16	1.56	.88	3.52	(-.3136, 3.4386)
Difference		-.51	1.34		(-3.2367, 2.2170)

ear over time for both groups.

For the SRT difference score for the worse ear at years 1 and 2, the interquartile ranges rather than the confidence intervals were examined (see Fig. 3) as the assumption of a normal distribution was not met. Note that the IQ range encompasses 0 for the SRT difference score for the worse ear at years 1 and 2 for both groups (although just barely for the experimental aided group), consistent with the absence of a significant change in the median SRT for the worse ear from year 0 to year 1 or from year 0 to year 2 for both groups.

W-22 WRS

The initial (year 0) mean W-22 WRS for the worse ear was 74.2% for the control unaided group and 62.8% for the experimental aided group; for the better ear, it was 94.4% for the control unaided group and 92.3% for the experimental aided group. The results of parametric two-sample (control group vs. experimental group) *t*-tests based on the unequal variance assumption are significant *(p* = .0001) at year 1, indicating that the absolute mean W-22 difference score for the worse ear was greater for the control unaided group than the experimental aided group at year 1 (df = 46.9974, *t* = 4.1397). From baseline to year 1, the mean W-22 WRS for the worse ear declined by 7.9% for the control unaided group, whereas it improved by 3.8% in the experimental aided group (see Table 4).

The results of parametric two-sample (control group vs. experimental group) *t*-tests based on the equal variance assumption are significant at year 2, indicating that the absolute mean W-22 difference score for the worse ear was significantly greater for the control unaided group than the experimental aided group at year 2 (df = 33, *t* = 5.5869, *p* = .0000). From baseline to year 2, the mean W-22 WRS for the worse ear declined by 17.3% for the control unaided group, whereas it improved by 6.2% in the experimental aided group (see Table 4).

For the W-22 difference score of the better ear at year 1, the assumptions of normal distribution and equal variances were not met, so the two-sample (control vs. experimental group) Wilcoxon Rank Sum (Mann-Whitney) Test was performed on the median W-22 difference scores. The results revealed the absence of significant differences

Table 4. Means, Standard Errors (SEs), Standard Deviations (SDs), and 95% Confidence Intervals (95% CIs) for the W-22 Difference Score at Years 1 and 2 for the Worse Ear

Group	N	Mean	SE	SD	95% Confidence Interval
Year 1					
Experimental	21	3.81	1.83	8.39	(-0.0087, 7.6278)
Control	28	-7.86	2.14	11.34	(-12.2539, -3.4604)
Difference		11.67	2.82		(5.9971, 17.3362)
Year 2					
Experimental	19	6.21	2.86	12.47	(0.2001, 12.2210)
Control	16	-17.25	3.07	12.26	(-23.7835, -10.7166)
Difference		23.46	4.20		(14.9172, 32.0038)

in the median W-22 difference score for the better ear between groups at year 1 (z = -0.955). The results of parametric two-sample (control vs. experimental group) t-tests (assumptions of equal variances and normal distribution were met) are nonsignificant for the better ear at year 2 (df = 33, t = -0.6110). Thus, the median and mean W-22 difference scores for the better ear at years 1 and 2, respectively, were similar for both groups. In the better ear at year 2, the mean W-22 difference scores of 0.5% in the experimental aided group and 1.8% in the control unaided group reflect essentially no change in mean W-22 WRS over time in these groups (see Table 5).

The changes over time on the median W-22 difference scores at year 1 and year 2 for the worse and better ears of the experimental aided and control unaided groups are shown in Figure 4. Note that the median W-22 difference score for the worse ear decreased substantially over time in the control unaided group, whereas it increased slightly in the experimental aided group. This is consistent with the presence of a deprivation effect for the worse ears of adults with asymmetric hearing impairment who were not fitted with amplification. The increasingly negative difference score over time in the worse ears of the control unaided group reflects a decline on the median W-22 WRS from the initial test to year 1 and from the initial test to year 2. In marked contrast, the median W-22 difference score slightly increased over time for the worse ears of the experimental aided subjects, reflecting slight improvement in the W-22 WRS over time. This finding suggests that amplification prevents deprivation effects on suprathreshold word-recognition performance in adults with asymmetric sensorineural hearing impairment. These prospective findings of a deprivation effect in the unaided ears and the absence of such an effect in the aided ears substantiate Silverman and Emmer's (1993) retrospective findings for their 16 participants (eight control unaided participants and eight experimental aided participants with asymmetric sensorineural hearing impairment).

The poorer initial (year 0) mean W-22 WRS for the worse ear in the experimental aided group (62.8%) than in the control unaided group (74.2%) suggests that persons with asymmetric hearing impairment were more likely to receive amplification if they had poor W-22 WRSs. To examine whether the deprivation effect in the control unaided group could be partially explained by a mean W-22 score that was lower at baseline for the experimental aided subjects than for the control unaided subjects, the decline was examined for the participants in the control unaided group who had initial W-22 WRSs below or equal to the median value of 77%. The results are shown in Table 6.

As shown in Table 6, when the control unaided participants with initial W-22 scores

Table 5. Means, Standard Errors (SEs), Standard Deviations (SDs), and 95% Confidence Intervals (95% CIs) for the W-22 Difference Score at Year 2 for the Better Ear

Group	N	Mean	SE	SD	95% Confidence Interval
Experimental	19	0.53	1.40	6.10	(-2.4159, 3.4685)
Control	16	1.75	1.41	5.65	(-1.2612, 4.7612)
Difference		-1.2237	2.00		(-5.2984, 2.8511)

Table 6. Means, SDs, and N for the W-22 WRS for the Worse Ear

Group	Year	N	Mean (%)	SD (%)
Experimental	0	21	62.8	24.1
	1	21	66.6	21.5
	2	19	68.2	22.8
Control	0	14	59.9	15.1
	1	14	54.3	14.2
	2	10	39.8	14.4

Note: Participants in the control group with initial W-22 WRSs greater than or equal to the median value of 77% were excluded.

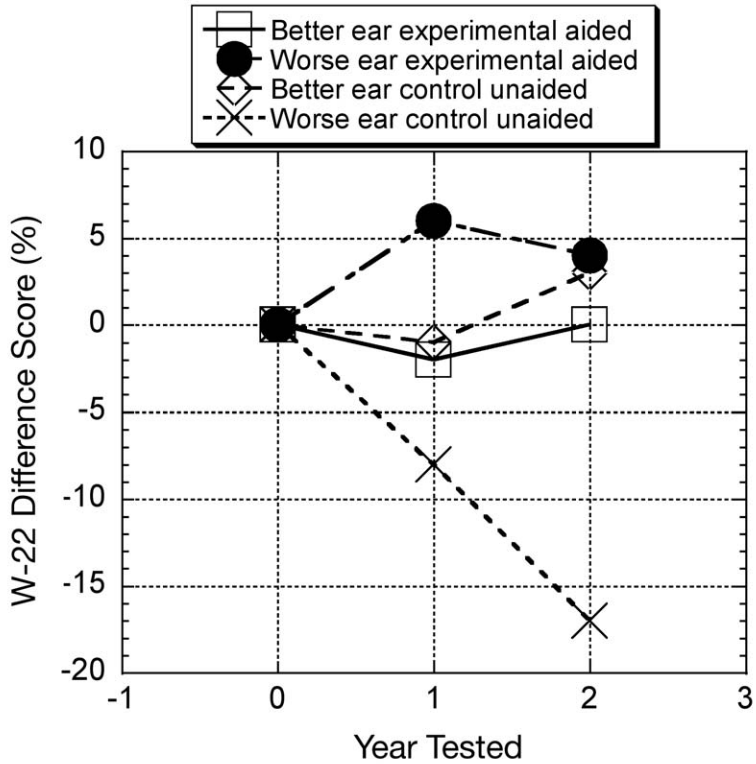

Figure 4. The median W-22 difference scores for the better ears of the experimental aided group (line connecting boxes), better ears of the control unaided group (line connecting diamonds), worse ears of the experimental group (line connecting filled circles), and worse ears of the control group (line connecting Xs) at baseline (year 0), year 1, and year 2.

for the worse ear that exceeded the median score at the initial test were excluded, the means of the two groups became similar at year 0, with a slightly lower (2.9%) mean for the control unaided than experimental aided participants. The magnitude of the mean decline from year 0 to year 2 for the subgroup of the control unaided participants who had initial scores below the median value was 20.1%, as compared with a mean improvement of 5.5% in the experimental aided participants. Thus, the deprivation effect in the control aided group is not attributable to a lower mean W-22 score in the experimental aided than in the control unaided group at the initial test. This conclusion is buttressed by the observed slight improvement, rather than smaller decline, in the experimental aided ears.

The W-22 difference scores for the worse ears at years 1 and 2 for both groups and for the better ears at year 1 for the experimental group and at year 2 for both groups are distributed normally so they meet the assumption for the use of confidence intervals. The W-22 difference score for the better ears of the control group at year 1 are not distributed normally. The confidence intervals for the W-22 difference score are shown in Table 4 for the worse ear at years 1 and 2 and in Table 5 for the better ear at year 2.

Inspection of the 95% confidence interval for the difference between groups in the mean W-22 difference score for the worse ear shows that it does not contain 0 at year 1 or 2, lending support to the finding of a significant difference between groups in the mean W-22 difference score for the worse ear at years 1 and 2. The confidence intervals for the W-22 difference scores for the worse ear at years 1 and 2 for the two groups did not overlap at all, providing further support for the finding of a significant difference between groups in the mean difference score. At years 1 and 2 for the worse ear of the control unaided group, the confidence interval did not contain 0, consistent with a significant decline in the W-22 WRS from baseline to year 1 and from baseline to year 2. At year 1 for the worse ear of the experimental aided group, the confidence interval contained 0, consistent with the absence of a significant change in W-22 WRS from baseline to year 1. At year 2, the confidence interval did not contain 0 (although it came close to 0), consistent with a slight, but significant, improvement in W-22 WRS from baseline to year 2 for the worse ear of the experimental aided group. Thus, the slight, but nonsignificant, improvement at year 1 became significant at year 2 for the worse ear of the experimental aided group.

For the W-22 difference score for the better ear, the interquartile ranges rather than the confidence intervals were examined at year 1 (see Fig. 5) as the assumption of normal distribution was not met. Note that the IQ range encompasses 0 for the W-22 difference score for the better ear at year 1 for both groups (although it just barely included 0 for the experimental aided group), suggesting that the median W-22 for the better ear did not change significantly from year 0 to year 1 for either group.

Inspection of the 95% confidence interval for the difference between groups in the mean W-22 difference score for the better ear shows that it contains 0 at year 2, lending support to the finding of no significant difference between groups in the mean W-22 difference score for the better ear at year 2. The confidence intervals for the W-22 difference scores for the better ear at year 2 for the two groups substantially overlapped, providing further support for this conclusion. At year 2 for both groups, the 95% confidence interval contained 0, consistent with the absence of significant changes in the mean W-22 difference score over time for the better ear within each group.

The chi-square test of independence of rows and columns was computed on the percent of ears showing significant declines in W-22 score at year 1 and at year 2. A decline was considered significant if the score at baseline differed from the score at year 1 or year 2 according to the 95% critical differences limits for 50-word lists (Thornton and Raffin, 1978). For the chi-square tests, all exact options were obtained. The results of chi-square tests (Fisher's Exact) for the W-22 score in the better ear at year 2 were nonsignificant for both years 1 and 2. Thus, the proportion of ears demonstrating significant decline on W-22 WRS did not differ significantly between groups for the better ear at year 1 or 2. The results of chi-square tests (Fisher's Exact) for the W-22 score for the worse ear were nonsignificant at year 1 but were significant at year 2 ($p = .005$). Thus, the percentage of worse ears that showed significant declines at year 2 on the W-22 WRS (beyond the 95% critical difference limits) was significantly higher for the control unaided group (43.8%) than for the experimental aided group (5.3%).

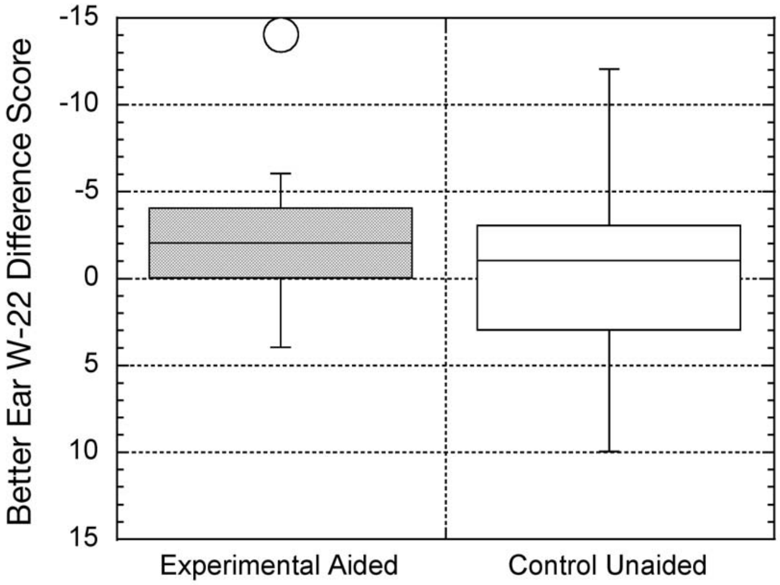

Figure 5. The box and whisker plots show the interquartile range (Q1 to Q3) for the W-22 difference score at year 1 for the better ear for both groups. The horizontal line inside the box represents the median W-22 difference score for the worse ear for both groups. The whiskers represent the range from +1.5X the IQ to -1.5X the IQ. The circle represents an outlier.

DISCUSSION

The purpose of this investigation was to prospectively evaluate performance on the pure-tone air-conduction thresholds, SRTs, and W-22 WRSs over time (one and two years from baseline) in aided and unaided adults with asymmetric sensorineural hearing impairment. Gatehouse (1992), in his prospective investigation, demonstrated auditory-deprivation effects over a 12-week period post-hearing-aid-fitting in a small sample (n = 4) of monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment. In their large-sample prospective investigation, Silman et al (1993) documented auditory deprivation findings in a similar population at one year postfitting. This large-sample study expands on the findings of Gatehouse and Silman et al by prospectively demonstrating auditory deprivation effects at two years postfitting; it also represents the first prospective investigation of auditory deprivation associated with lack of amplification in adults with asymmetric sensorineural hearing impairment.

The finding of a lack of auditory deprivation effect on the SRT and PTA substantiates the findings of earlier studies (Silman et al, 1984; Gelfand et al, 1987; Stubblefield and Nye, 1989; Burkey and Arkis, 1993). Stubblefield and Nye (1989) found increases in the PTA and SRT over time, but the increases were equivalent for the two ears, consistent with an aging rather than auditory deprivation effect, as the participants were seen three to six years post–initial test. In this study, the increase in the PTA was significant, although slight, over time for the better ears. The increase in PTA for the better ears was similar for both groups. Despite the slight increase in the PTA for the better ears, recall that no significant decrease was observed on suprathreshold word-recognition performance for the better ears in either group. The lack of an auditory deprivation effect for the SRT and PTA provides further support for the conclusion that the auditory deprivation effect is seen for suprathreshold speech recognition measures rather than pure-tone or speech-recognition threshold measures.

For the W-22 WRS, the results revealed the following: For the worse ear, the mean difference score was significantly greater for the control unaided group than for the experimental aided group at years 1 and 2. The confidence interval for the mean difference between groups in W-22 difference score for the worse ear did not contain 0 at years 1 and 2. The confidence interval for the mean W-22 difference score for the worse ear contained the value of 0 for the experimental aided but not control unaided group at year 1; at year 2, the confidence interval failed to include 0 for both groups, consistent with a significant decline in the mean W-22 WRS for the control unaided group and slight, although significant, improvement in the mean W-22 WRS for the experimental aided group. Considered together, these findings reflect significant decline at one and two years postfitting in the W-22 word-recognition ability in the worse ears of the control unaided group but not in the worse ears of the experimental aided group, consistent with the presence of auditory deprivation associated with lack of amplification in the control unaided group. For the worse ears of the experimental aided ears, the findings also show improvement over time that was nonsignificant at year 1 but significant by year 2, possibly reflecting reversal of auditory deprivation effects (prior to entering the study) with amplification, which has been referred to as recovery (Silverman and Silman, 1990; Silverman and Emmer, 1993). Silverman and Emmer had reported significant improvement in speech-recognition ability over time for the worse ear of two of their eight aided participants with asymmetric sensorineural hearing impairment.

In contrast, for the better ear, the mean/median W-22 difference score did not differ significantly between groups at either year 1 or year 2, and the confidence interval/interquartile ranges for both groups contained the value of 0 at years 1 and 2. These findings reflect absence of significant changes over time in mean/median W-22 word-recognition ability for the better ears of both groups, consistent with the absence of auditory deprivation.

The decline in the W-22 WRS in the worse ears of the control unaided but not experimental aided group suggests that auditory deprivation occurs in the worse ears of unaided adults with asymmetric sensorineural hearing impairment, analogous to the findings of auditory deprivation in the unaided ears of monaurally fitted adults with bilateral, sensorineural hearing impairment. The changes in the W-22 WRS from initial test to final test in the worse ears of the experimental aided and control unaided subjects with asymmetric sensorineural hearing impairment, based on the results of this investigation, and in the unaided versus aided ears of monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment, based on the findings of Silman et al (1984), are displayed (see Fig. 6). Note that the decline is essentially equivalent for the worse ears of the asymmetric control unaided group and for the unaided ears of the monaurally fitted bilateral group, despite the shorter interval between tests (two years) for the asymmetric group as compared with the longer interval between tests (four to five years) for the bilateral group. The similar declines for both groups (asymmetric unaided and monaurally fitted bilateral) supports the parallel drawn by Hood (1990) between individuals with unilateral or asymmetric sensorineural hearing impairment and monaurally fitted individuals with symmetric, bilateral sensorineural hearing impairment. Silman et al (1984) did not examine performance at two years postfitting, so it cannot be determined whether the deprivation effect in that study was progressive over the four-to-five-year period. If the deprivation effect is progressive and does not plateau beyond two years, then the finding of a 17.3% decline in W-22 WRS at two years postfitting suggests a stronger deprivation effect for unaided adults with asymmetric sensorineural hearing impairment than for monaurally fitted adults with bilateral symmetric sensorineural hearing impairment. In such a case, the asymmetry in audiometric configuration is greater or more longstanding than the asymmetry in auditory stimulation associated with monaural amplification of individuals with symmetric, bilateral sensorineural hearing impairment. On the other hand, if the deprivation effect plateaus at two years, then the finding of a 17.3% decline in the asymmetric study suggests that the deprivation effect is similar for unaided adults with asymmetric sensorineural hearing impairment and for monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment. Evidence to suggest, however, that the auditory deprivation effect is progressive beyond year 2 comes from the results of several studies that show

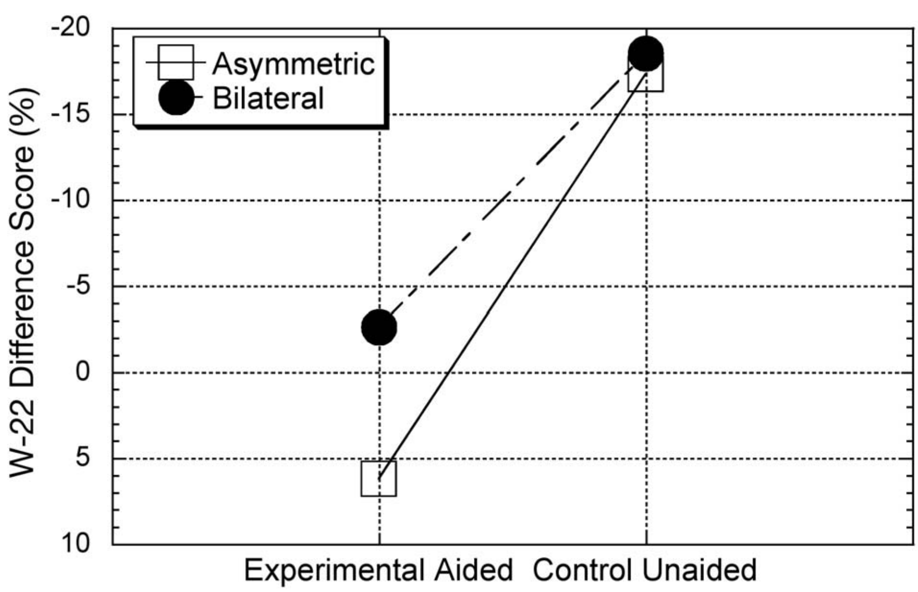

Figure 6. Mean W-22 difference score at the final test for the control unaided subjects and experimental aided subjects for the study on asymmetric hearing impairment reported here and the study on adults with bilateral symmetric hearing impairment (Silman et al, 1984). The mean W-22 difference score represents the year 2 score minus the baseline score for the asymmetric study and represents the score at four to five years post-baseline for the bilateral, symmetric study.

progressive declines over time in the unaided ears of monaurally fitted adults with bilateral, symmetric sensorineural hearing impairment (Silverman, 1989; Silverman and Silman, 1990; Hurley, 1993, 1998, 1999; Gelfand, 1995).

The percent of worse ears with significant declines on the W-22 WRS was 43.8% at year 2 for the unaided adults with asymmetric hearing impairment in this study, similar to the 39% of the unaided ears of monaurally aided adults with bilateral, symmetric sensorineural hearing impairment reported by Silman et al (1984); this contrasts with the 80% of the worse ears of the eight unaided adults with asymmetric sensorineural hearing impairment reported by Silverman and Emmer (1993). Sample size and test interval differences may account for these different proportions.

A limitation of this study was the rate of attrition. The rate of attrition from year 0 to year 2 was 9.5% for the experimental aided group versus 42.9% in the control unaided group. The question could be raised whether the observed deprivation effect in the control group at year 2 occurred because the magnitude of the decline for the dropouts was less than that for the participants who did not drop out, thereby yielding a large W-22 difference score at year 2. To attempt to answer this question, the mean difference scores at year 1 were obtained for the control participants who dropped out after year 1 and at year 1 for the control participants who did not drop out after year 1. The results revealed a mean W-22 difference score for the worse ear at year 1 of -6.8% for the participants in the control group who did not drop out versus -6.5% for the participants in the control group who did drop out. Essentially, no difference in mean W-22 difference score for the worse ear existed between the two groups, so the measured deprivation effect did not result from attrition.

These results support the clinical practice of amplification of the worse ears of adults with asymmetric sensorineural hearing impairment. Future research is needed to prospectively examine the changes in suprathreshold speech-recognition performance over an expanded time window in aided and unaided adults with asymmetric sensorineural hearing impairment.

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