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Efficacy of the Cued-Listening Task in the Evaluation of Binaural Hearing Aids

James Jerger*
Rieko Darling*
Eric Florin*

Abstract

To evaluate the efficacy of the cued-listening task (CLT) in the evaluation of binaural hearing aid performance, we tested 10 experienced binaural hearing aid users. Subjects listened for a speech target embedded in continuous discourse from either the right or left directions while simultaneously suppressing similar continuous discourse from the other direction. The task was carried out in the presence of multitalker babble from an overhead source. The target-to-babble ratio was always 0 dB. Testing was carried out in four conditions: (1) unaided; (2) aided in right ear; (3) aided in left ear; and (4) aided binaurally. Results showed that neither condition of monaural amplification was significantly better than the unaided condition. Under binaural amplification, however, there was a significant improvement in target recognition. Furthermore, this enhancement in performance was significantly greater when targets came from the right side than when they came from the left side.

Key Words: Binaural, cued listening, hearing aids, right-ear advantage

One of the most important theoretical advantages of binaural hearing aids is the enhancement of the ability to understand speech in the presence of competing background noise (Markides, 1977; Johnson, 1987; Day et al, 1988). It is assumed that the binaural auditory system underlies such ability in the normal case and that binaural amplification is requisite to the recapture of such ability in the individual with bilateral hearing loss. In the clinical situation, however, it has been difficult to document, objectively, a significant advantage for binaural fittings (Grimes et al, 1979, 1981; Erdman and Sedge, 1981, 1986; Schreurs and Olsen, 1985). This may derive from the fact that conventional techniques for the behavioral evaluation of hearing aid performance have traditionally emphasized monosyllabic word recognition, either in quiet or against a background of relatively time-invariant noise, rather than the ability to focus on a speech target while suppressing competing speech.

The purpose of the present study was to compare binaural with monaural amplification on the cued-listening task (CLT), a newly devised technique stressing the listener's ability to attend selectively to a precued speech target while simultaneously suppressing irrelevant competing speech and background voice babble (Jerger and Jordan, 1992). We sought to determine whether such a testing paradigm could provide the basis for a more complete understanding of the actual benefit to be derived from binaural amplification in situations where background noise challenges effective speech communication by hearing-impaired individuals.

METHOD

Subjects

Ten binaural hearing aid users served as the subjects of this prospective investigation. Their characteristics are summarized in Table 1. Subjects ranged in age from 48 to 88 years. Average age was 74.1 years. There were eight males and two females. Nine subjects were right handed, one was left handed. In all cases, the loss was sensorineural. Audiometric con-

*Division of Audiology & Speech Pathology, Baylor College of Medicine, Houston, Texas
Reprint requests: James Jerger, 11922 Taylorcrest, Houston, TX 77024

Table 1 Selected Characteristics of the 10 Experimental Subjects

Subject	*Age*	*Sex*	*Handedness*	*PTA-RE*	*PTA-LE*	*PB-RE*	*PB-LE*	*Months of Use*
HK	83	M	R	58	58	60	60	43
RS	78	M	R	52	50	36	48	36
VH	70	M	R	58	48	8	12	19
AK	88	F	R	47	43	96	76	24
LM	79	M	R	40	58	60	32	48
JG	70	M	R	53	42	96	84	1
AS	85	M	L	38	47	56	40	24
DP	67	M	R	60	55	8	20	60
RF	73	M	R	47	47	76	72	68
PJ	48	F	R	58	45	24	64	3
Mean	74.1			51.1	49.3	52.0	50.8	32.6

PTA = pure-tone average; RE = right ear; LE = left ear; PB = phonemically balanced.

tour was either flat or gradually sloping from low to high frequencies. Average audiograms for the two ears are plotted in Figure 1. The pure-tone average (PTA) hearing threshold level (averaged across 500, 1000, and 2000 Hz) ranged from 38 to 60 dB in the right ear and from 42 to 58 dB in the left ear. The mean PTA was 51.1 dB for the right ear and 49.3 dB for the left ear. In view of subsequent aided results, it is noteworthy that the left ear did not show more average loss than the right ear. Indeed, degree of loss was, if anything, slightly greater in the right ear. In all cases, the degree of loss was similar in the two ears. The interaural difference between PTAs never exceeded 18 dB.

Mean unaided monosyllabic phonemically balanced (PB) word-recognition scores (maximum of performance-versus-intensity function, or PB max) were 52.0 percent for the right ear (with a range from 8% to 96%), and 50.8 percent for the left ear (with a range from 12% to 84%).

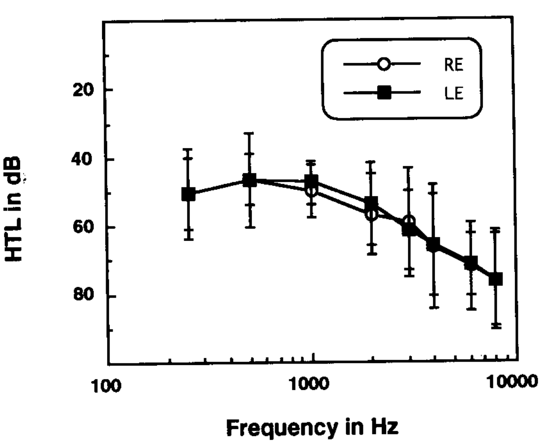

Figure 1 Average air-conduction audiograms of the right and left ears of the 10 experimental subjects. Error bars encompass ± 1 standard deviation.

Neither the interaural PTA difference nor the interaural PB max difference was statistically significant by paired t-test.

All subjects had been binaural aid users for a minimum of 1 month. Actual binaural usage varied from 1 to 68 months. Seven subjects wore behind-the-ear aids, and three subjects had been fitted with in-the-ear aids. All subjects were tested in the aided conditions while wearing their own aids.

Apparatus and Procedure

Figure 2 shows the arrangement of the experimental apparatus for the CLT (Jerger and Jordan, 1992). All testing was carried out in

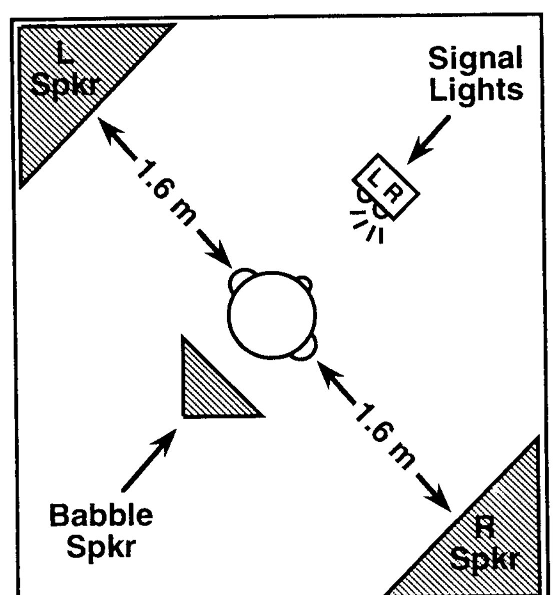

Figure 2 Arrangement of apparatus for the cued-listening task.

one experimental session lasting about 30 minutes. The subject was seated in the center of the sound-treated room, equidistant between two loudspeakers, one directly to his/her right (azimuth = 90 degrees) and the other directly to his/her left (azimuth = 270 degrees). A third loudspeaker was mounted on the ceiling directly above his/her head.

Performance was evaluated first in the unaided condition, then in each of the three aided conditions. The order in which the latter three conditions was executed varied randomly from subject to subject. For all aided conditions, the subject adjusted the volume control of each aid to comfort level in response to continuous discourse played diotically from both speakers. In addition, in the binaural aided condition, the subject readjusted both aids to achieve both comfort level and interaural balance. In all testing, both unaided and aided, the speech intensity level from each loudspeaker was held constant. In 9 of the 10 subjects, the level was 60 dB SPL. In the tenth subject, DP, who had the greatest degree of loss, the level was set at 70 dB SPL for all testing.

In the four experimental measures, continuous discourse of a male talker reading an adventure story, written in the first person, was presented to both the left and right loudspeakers. The story from one loudspeaker was offset by about 60 seconds relative to the story from the other loudspeaker. Thus, different parts of the same story were presented simultaneously from the left and right sides. The patient responded by pressing a response button each time he/she heard the personal pronoun "I" from the direction cued by a signal light. Multitalker babble was played through the loudspeaker mounted above the patient's head. The ratio of target signal to babble level (MCR) was always 0 dB (measured at a point in space equivalent to the center of the subject's head). For each condition (unaided, right ear aided, left ear aided, both ears aided), we presented 100 target "I"s, 50 from the patient's right and 50 from his/her left. The 50 targets from a particular side were presented in 5 blocks of 10 targets each. The order in which the 10 blocks (5 from the right, 5 from the left) were presented was quasirandomized with the constraint that no condition (listen right or listen left) was presented more than twice in succession. The direction from which the targets came in a particular block was precued to the patient by one of two signal lights, one labelled "listen right" and the other labelled "listen left." There were two response buttons, one for right-sided targets, the other for left-sided targets. A response was accepted and scored as correct if it occurred within a 1.5-second interval following onset of the "I" target from the correct side. Each subject was tested in a single session lasting about 30 minutes.

Group Differences. Statistical evaluation of group differences between unaided and aided conditions was effected by a one-factor, repeated-measures analysis of variance (ANOVA). For these analyses, performance in a particular aided or unaided condition was collapsed across target direction. There were 3 degrees of freedom for condition and 27 degrees of freedom for residual error. For post-hoc paired comparisons among means, the Scheffe F-test was used. Comparison of laterality effects in target-right and target-left conditions in a particular treatment condition was accomplished by paired t-tests of mean performance differences for the two target directions.

Individual Differences. Statistical evaluation of differences between the unaided and the aided conditions, on an individual basis, was effected by a nonparametric randomization test elaborated by Edgington (1967). In each treatment condition, there were 10 estimates of hit rate, 5 in the target-right condition and 5 in the target-left condition. In order to collapse across target direction, successive pairs of target-right and target-left scores were averaged. This yielded five mean performance scores in the unaided condition and five mean scores in each of the aided conditions. In Edgington's randomization test, the variability among these means provides the estimate of error variance against which to evaluate the treatment effect (aided versus unaided).

For the analysis of both group and individual effects, statistical significance was evaluated at an alpha level of 0.05.

RESULTS

Illustrative Cases

The following two cases illustrate the range of binaural performance advantages observed on the CLT. Figure 3 summarizes results for subject VH, a 70-year-old, right-handed man with a moderately severe bilateral sensorineural loss, slightly greater in the right ear. VH has been a successful user of binaural, behind-the-

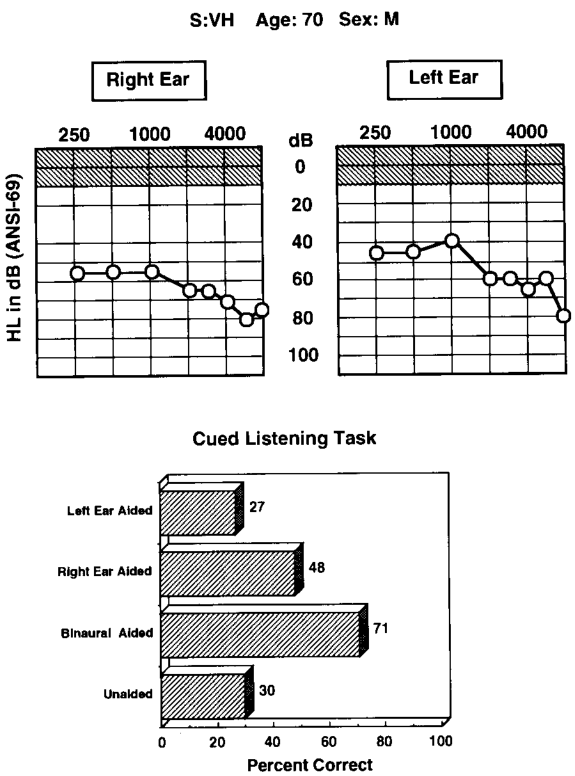

Figure 3 Results in subject VH: upper panels, pure-tone audiograms; lower panel, aided and unaided results on cued-listening task.

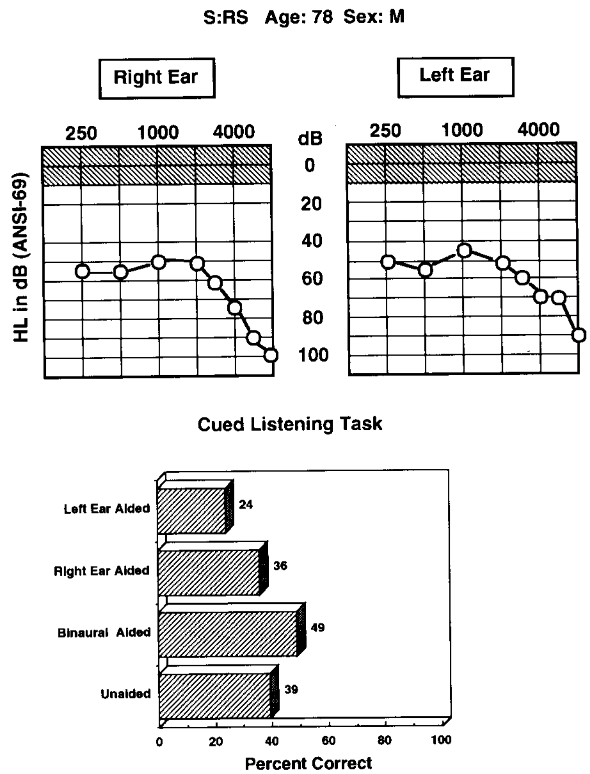

Figure 4 Results in subject RS: upper panels, pure-tone audiograms; lower panel, aided and unaided results on cued-listening task.

ear aids for 19 months. The upper panels of Figure 3 show the pure-tone, air-conduction audiograms. The lower panel summarizes results on the CLT test. Not unexpectedly, the unaided score was relatively low, 30 percent. When the left ear was aided, performance actually decreased to 27 percent. When the right ear was aided, performance improved to 48 percent. Finally, when both ears were aided, performance increased further to 71 percent. The improvement under binaural amplification was a dramatic 41 percent, a significant difference on the randomization test ($p < .05$).

Figure 4 summarizes findings on subject RS, a 78-year-old, right-handed man with an audiometric picture (Fig. 4, upper panels) similar to VH. RS has been a relatively less successful user of binaural, behind-the-ear aids for 36 months. On the CLT procedure (lower panel of Fig. 4), subject RS scored at about the same level as subject VH in the unaided condition (39%). In both monaural aided conditions, however, performance was actually slightly poorer than in the unaided condition (24% when the left ear was aided; 36% when the right ear was aided). Only in the binaural aided condition did performance improve (49%), but the aided advantage was only 10 percent. This 10 percent difference was, however, significant on the randomization test.

These two cases illustrate the range of significant binaural advantages observed in our sample of binaural aid users. It is perhaps noteworthy that neither the pure-tone audiometric configurations nor the unaided monosyllabic word scores (see Table 1) would have predicted the differences between these two subjects on the CLT.

Group Performance

Figure 5 summarizes mean percent correct scores under the four experimental conditions, collapsed across the target-right and target-left directions. In the unaided condition, overall performance was 39.8 percent. When the left ear was aided monaurally, overall performance was not much improved over the unaided condition (0.4%), and when the right ear was aided, there was only a slight overall improvement (4.1%) relative to the unaided condition. When the subjects were aided binaurally, however, there was substantial improvement in overall performance (13.8%). A repeated-measures

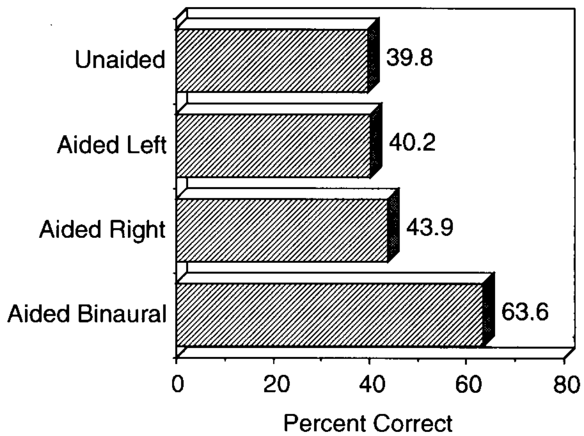

Figure 5 Average aided and unaided results of the 10 experimental subjects, collapsed across target direction.

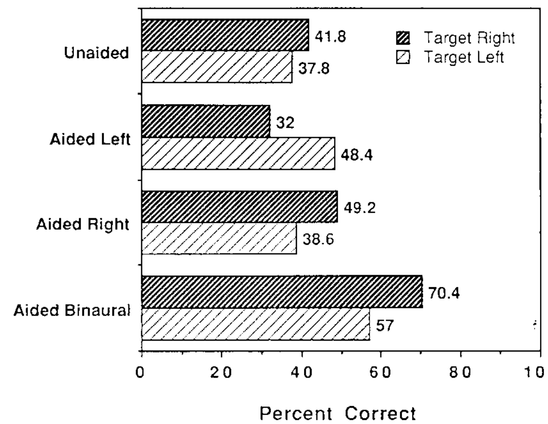

Figure 6 Average aided and unaided results for right- and left-direction targets.

analysis of variance (ANOVA) yielded a significant condition effect ($F = 12.437$, $p < .05$). Post-hoc paired comparisons (Scheffe F-test) were significant for unaided versus binaural aided ($F = 9.19$, $p < .05$), right aided versus binaural aided ($F = 6.307$, $p < .05$), and left aided versus binaural aided ($p < .05$), but for no other comparisons. In other words, the binaural condition was significantly better than all other conditions, aided or unaided, but neither the right aided nor the left aided conditions were significantly different from the unaided condition. In this CLT, only binaural amplification was significantly better than no amplification at all. Neither monaural aided condition was significantly better than the unaided condition.

Analysis according to Target Direction

Figure 6 summarizes group results according to target direction. In the unaided condition, there was a 4 percent advantage when the target came from the right side. In the two monaural conditions, there was laterality asymmetry in the expected directions. When the left ear was aided, for example, performance was 16.4 percent better when the target came from the left side, and, when the right ear was aided, performance was 10.6 percent better when the target came from the right side. Interestingly, however, when both ears were aided, the advantage enjoyed by targets coming from the right side grew to 13.4 percent. Paired students' t-tests revealed that the target-direction effect was significant only in the binaural aided condition. When both ears were aided, performance was still significantly better when the target came from the right side than when it came from the left side.

Individual Subject Analysis

The foregoing analyses of the CLT data show that, as a group, the 10 individuals in this sample fared better with binaural aids than with monaural aids. From the standpoint of clinical evaluation, however, it is relevant to ask to what extent the CLT technique reveals significantly improved performance on an individual basis. In other words, having evaluated a single individual in the unaided and binaural aided conditions, can we say that aided performance is significantly better than unaided performance? Stated differently, is the group effect sufficiently robust that it carries over to evaluation of the data for a single subject? The CLT procedure was designed to permit such individual comparisons. Using the nonparametric randomization test for single-subject data, elaborated by Edgington (1967), we have carried out a separate statistical analysis of each subject, comparing the unaided and binaural aided conditions, collapsed across target direction. Table 2 summarizes these results. A total of 7 of the 10 subjects showed statistically significant improvement in individual performance between the unaided and binaural aided conditions. Careful examination of the characteristics of the 3 subjects who did not show a significant difference failed to reveal a consistent pattern of difference from the 7 who did. They were distinguished neither by age, degree of overall loss, degree of low-frequency loss, unaided PB max scores, or months of binaural use.

Table 2 Statistical Comparison of Unaided and Binaural Aided Performance* by Individual Subject

Subject	Unaided	Binaural Aided	Binaural Advantage	Significant Difference
HK	13	45	32	Yes
RS	39	49	10	Yes
VH	30	71	41	Yes
AK	48	54	6	No
LM	19	60	41	Yes
JG	76	79	3	No
AS	65	69	4	No
DP	46	60	14	Yes
RF	48	75	27	Yes
PJ	14	75	61	Yes

*Percent correct target hit rate.

DISCUSSION

The present results demonstrate that the CLT is an effective technique for demonstrating the advantage of binaural hearing aid fittings. Indeed, as shown in Figure 5, only in the binaural condition did the group show significantly better performance than in the unaided condition. Neither monaural fitting was particularly efficacious.

Our original aim in the design of the CLT (Jerger and Jordan, 1992) was to simulate, under controlled laboratory conditions, one of the kinds of listening situations about which hearing aid users, especially elderly persons, typically complain (i.e., listening to one talker while trying to suppress the competing speech of other talkers). In the real world, such situations are almost always characterized by some degree of directionality. That is, the to-be-attended target voice is coming from a particular direction, and the competing speech is coming from a different direction. It is not surprising that binaural aids should be helpful in such situations since one of the principal contributions of binaural hearing is directionality. The clinical evaluation of hearing aid performance, however, seldom takes this important dimension of everyday communication into account. Hence, it has been difficult to document, objectively, the efficacy of binaural amplification. The CLT appears to provide such a vehicle for accountability.

The fact that performance in the binaural condition was significantly better when the target came from the right side is consistent with previous findings on dichotic listening in the elderly. Results from both the dichotic sentence identification test (Jerger et al, in press) and the CLT (Jerger and Jordan, 1992) have reflected a greater age-related decline in left-ear performance than in right-ear performance in the dichotic paradigm. In the present data, this effect was small in the unaided condition, but increased to almost 14 percent when both ears were aided. The exact basis for this relative left-ear decline is not known, but age-related decrease in the efficiency of interhemispheric transfer via the corpus callosum has been described (Goldstein and Braun, 1974).

From the standpoint of clinical evaluation, the CLT has the important property that it can yield an estimate of the statistical significance of the difference between aided and unaided performance at the level of the individual subject. This has two important implications. First, it may be possible to address the important issue of accountability in hearing aid dispensing with a greater degree of confidence and objectivity than has heretofore been possible. Second, the CLT may provide a paradigm for the evaluation of unique performance features (e.g., adaptive filtering, novel compression circuitry, etc.) of both existing and future amplification systems.

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