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Performance of postlinguistically deaf cochlear implant patients on the connected speech test (version 3)

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PERFORMANCE OF POSTLINGUISTICALLY DEAF COCHLEAR IMPLANT PATIENTS ON THE CONNECTED SPEECH TEST (VERSION 3)

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INTRODUCTION

The benefit provided by hearing aids or a cochlear implant can be quantified by evaluating an individual's performance on sentence tests in the following conditions: audition-only, vision-only and audition-plus-vision. Scores on sentences presented in the audition-only and vision-only conditions reflect the individual's ability to identify words from signals delivered to these two sensory modalities separately. In everyday life, people communicate more often when auditory and visual (speech-reading) cues occur simultaneously. Consequently, one measure of benefit has been the difference in score between the audition-plus-vision and vision-only conditions. If the score is significantly higher in the audition-plus-vision condition, speech-reading is considered enhanced by hearing aid or cochlear implant use. If the score for audition-plus-vision is significantly higher than the sum of the scores for the audition-only and vision-only conditions, then synergistic benefit has been provided.

The CID Everyday Sentences test (Davis & Silverman, 1978) has been used for the evaluation of sensory aids for the deaf (hearing aids, cochlear implants and vibrotactile aids). This test can be presented live voice or with recordings, several of which are available (original and new videotape recordings from National Technical Institute for the Deaf: Johnson, 1974; video laser disc recording from the Johns Hopkins Lipreading Corpus: Bernstein & Eberhardt, 1986). With the recent introduction of the Multi-Peak speech processing strategy for the Nucleus Multi-

Electrode Cochlear Implant System (Skinner, Holden & Holden et al., 1991), a number of patients can accurately identify all or almost the key words in the CID Everyday Sentences in the audition-plus-vision condition. For these patients, more difficult material is needed to determine how much speechreading is enhanced by use of the cochlear implant.

The Connected Speech Test Version 3 was developed primarily to quantify hearing aid benefit by measuring the intelligibility of everyday speech in audition-only and audition-plus-vision conditions (Cox, Alexander, Gilmore, & Pusakulich, 1989). The female talker was chosen because her everyday speech, presented audition-only, is of average intelligibility (Cox, Alexander, & Gilmore, 1987), and she generates an average amount of speechreading cues when speaking (Cox et al., 1989). This talker speaks more rapidly and with less movement of her articulators (e.g., mouth, lips, jaw and tongue) than the talkers in the recordings of the CID Everyday Sentences mentioned above. However, her articulation rate of 4.8 syllables/sec (Cox et al., 1987) is within the range for normal spontaneous speech (4.4 to 5.9 syllables/sec; Goldman-Eisler, 1968).

Pilot data for the present study was obtained with two subjects implanted with the Nucleus device programmed for the Multi-Peak speech coding strategy to determine whether the Connected Speech Test Version 3 would be of appropriate difficulty to get less than perfect scores in the audition-plus-vision condition and above chance scores in the audition-only and vision-only conditions. Although both subjects said it was very

difficult to understand and speechread the talker, their scores fell within an appropriate range for all three conditions.

For the present study, data was obtained in the audition-plus-vision, vision-only and audition-only conditions with the 24 practice passages and 18 of the 48 test passages. The practice passages were used for training, and the test passages were used to evaluate performance. The data for the test passages were analyzed from two perspectives: the score variability (test-retest variability for passages as well as sets, and variability across the test and retest for passages and sets) and the benefit provided by the implant. This analysis addressed the following questions:

1. What is the score variability for the three conditions (audition+vision, vision-only and audition-only) for the individuals and the group?
2. Are the scores for the group and individuals significantly greater for the audition+vision condition compared with the vision-only condition, and how much enhancement of speechreading was provided by the cochlear implant?
3. Are the scores for the group and individuals significantly greater in the audition-plus-vision condition than the sum of the scores in the audition-only and vision-only conditions? That is, was there synergistic benefit when auditory and visual cues were presented simultaneously compared with auditory and visual cues each presented alone?

METHOD

Equipment/Test Environment

Nucleus Multi-Electrode Cochlear Implant

A recent publication by Clark et al. (1987) gives describes the implant, surgical implantation, function and patient performance with the Wearable Speech Processor. However, all the subjects in this study wore the Mini Speech Processor. There are definite differences in the size, weight, circuits and manner in which the two different processors convert incoming signals from the microphone into a digital code for electrical stimulation of the electrodes. A description of the Mini Speech Processor is given by Skinner et al. (1991).

The Mini Speech Processor can be programmed for several speech coding strategies, two of which are F0F1F2 and Multi-Peak. The FOF1F2 coding strategy allows the processor to extract the fundamental frequency (F0), along with the amplitude and frequency information of the first (F1) and second formants (F2) of speech. The stimulation rate of biphasic pulses is determined by the FO, and the current amplitude and electrode to be stimulated are determined by F1 and F2 (Clark et al., 1987). The Multi-Peak coding strategy extracts the information of the FOF1F2 coding strategy in addition to the amplitude of sound in three high-frequency bands (Band 3: 2000-2800 Hz; Band 4: 2800-4000 Hz; Band 5: 4000-6000 Hz).

Laboratory Equipment

A PDP-11/23+ computer interfaced to a custom-built audiological console was used to control presentation of the speech stimuli. A touch-display screen (Electro Mechanical Systems, Model TID) was used by the subject to control the presentation rate of the test stimuli used in the study, which will be described later. A video laser disc player (Pioneer, Model LD 6000 A) was used to play back the recorded sentences of the Connected Speech Test Version 3 through a 48-cm (19") monitor (Sony Trinitron, Model PVM-1900). The audio signal from the recordings was presented through a Urei loudspeaker (Model 809) that has a uniform frequency response (±3 dB) between 50 and 17,500 Hz. The sound pressure level (SPL) of the speech was measured with the microphone of the sound level meter at the center of where the subject's head would be during testing.

Test Room

The Connected Speech Test passages were presented in a double-walled sound booth (IAC, Model 1204-A; 254 cm x 264 cm x 198 cm) with the subjects sitting at 0° azimuth, 2 meters in front of the loudspeaker and video monitor.

Subjects

Information on the five subjects is given in Table 1; subjects 1 through 5 in the present study are the same as subjects 2, 3, 5, 6 and 7, respectively, in a study by Skinner et al. (1991). The amount of time of profound deafness is the time between confirmation of deafness at the better ear and implantation. All the subjects had the electrode array inserted 25 mm,

which is the desired depth, except for subject 2. Subject 2 had an insertion depth that was less than 25 mm due to resistance that occurred during the surgery. All except subject 5 had Mini Speech Processors that were programmed in the Bipolar+1 mode, which means that the stimulating electrode was separated from the ground or return electrode by 1.5 mm. With this type of electrode pairing, the maximum number of pairs is 20. Subject 5 was programmed with a Common Ground (CG) mode of electrode pairing. With this type of pairing, when an electrode is stimulated, the other 21 electrodes are coupled together as the indifferent or ground electrode. In this CG mode, the maximum number of pairs is 22. Three of the subjects used fewer electrodes than the maximum: subject 1 had one electrode pair that caused facial nerve stimulation; subjects 2 and 5 had two electrode pairs that produced unpleasant sound sensations. All subjects had their processors programmed with linear/logarithmic assignment of frequency boundaries to active electrodes (see Appendix C in Skinner et al., 1991), a noise cut-out level of zero (see Appendix B in Skinner et al., 1991), and Multi-Peak speech coding strategy for all except subject 1 who used the FOF1F2 coding strategy. Also, the MSP was programmed for Stimulus Level amplitude coding (see Appendix B in Skinner et al., 1991) for all subjects except subject 1, for whom the MSP was programmed for Current Level amplitude coding.

Test Materials

The first version of the Connected Speech Test (CST) was based on an evaluation with normal-hearing listeners of the audio-only portion of the audiovisual recording (Cox et al., 1987). Version 2 was based on an evaluation with hearing-impaired listeners of the same audio-only recording (Cox, Alexander, Gilmore & Pusakulich, 1988). The third and final version (CSTv3) was based on an evaluation with normal-hearing listeners of the auditory and visual portions of the original recordings (Cox et al., 1989). The third version of the CST was used in the present study.

The following direct quote from the Cox et al., 1989 article describes the recording of the CST:

> "The CST passages were recorded on videotape using a broadcast quality camera (Sony, Model DXCM3A with Fujinon lens). Lighting consisted of a 1000 watt back light, a 1500 watt key light and 1000 watt diffused fill light. The film was made in color against a grey background. The talker used light, everyday, makeup. These conditions were chosen to provide a clear but not excessively detailed picture, similar to typical everyday experience. The talker's head, neck and top of shoulders were photographed from a 0° azimuth. When replayed on a 33 cm diagonal monitor, the image is slightly smaller than life-sized. The edited master tape was dubbed to optical laser disk (Panasonic recorder, Model TQ2026F)."

The twenty-two practice passages of the CSTv3 were used to familiarize the subjects with the talker and provide training on the test. Eighteen of the 48 test passages of the CSTv3 were selected to evaluate test-retest variability and the benefit provided by implant use (that is, enhancement of speechreading

and synergistic benefit of audition-plus-speechreading). A list of the topic words for each passage pair and sets of four and six passages are shown in Table 2. The passages used in the present study included the topics "carrot" (passage 7) through "cactus" (passage 24); these topics were divided into the three designated sets of six. Each practice and test passage is of a topic known to the subject and consists of 10 sentences. In each passage, there are 25 key words that are used for scoring. An example of one of the passages is shown in Table 3.

Procedures

Processor Settings for Testing

Prior to data collection, each subject adjusted the sensitivity control on the Mini Speech Processor to a level where the sentences were clearest and most comfortable. Each subject used either the normal or noise-suppression position on the processor that they used in everyday life. Subjects 1 through 4 used the normal position, and subject 5 used the noise-suppression position.

Practice Sessions

Each subject participated in three practice sessions prior to the actual study. During the first practice session, the subjects were given 6 to 10 of the 22 practice passages; for subjects 2 and 3, only the audition-plus-vision condition was used, whereas for the other subjects audition-plus-vision, vision-only and audition-only conditions were used. During the second and third practice sessions, 10 passages were presented starting with the audition-plus-vision condition, then vision-

only, followed by audition-only, and repeating this sequence twice ending with an additional audition-plus-vision condition for all except subject 1. For subject 1, only the audition-plus-vision condition was used on the second practice session. Before each passage was presented, the topic was shown in large letters on the video monitor for the subjects to read. The subjects wrote down as many of the words as they could at the end of each sentence.

Test Sessions

Table 4 lists the presentation order of passages from the Connected Speech Test Version 3 for subject 2 for the test sessions. At the beginning of each session, one practice passage was presented in the audition+vision condition. During the first four sessions, test-retest variability was evaluated by presenting the same passages twice in each of the three conditions; that is, passages 7-12 were presented in the audition-plus-vision condition, passages 13-18 were presented in the vision-only condition, and passages 19-24 were presented in the audition-only condition. The passages for sessions 1 through 4 were presented in the same order to all subjects.

During the sessions 5 through 8, the sets of 6 passages were presented in each of the other two conditions so that all passages were presented in all three conditions. The assignment of passages to conditions, and the order in which the passages were presented within a condition, were pseudorandomized among the five subjects to minimize learning and fatigue effects.

It took each subject approximately one hour to complete

the 10 passages presented in each session and two sessions to complete a set of six passages in one condition. Sessions were scheduled one week apart.

Analysis of Data

The passages were scored for the number of correct key words out of 25. From this data, the passage score in percent correct and the passage score in rationalized arcsine units (Studebaker, 1985) were calculated. The transformation from percent correct to rationalized arcsine units (rau) is useful in equalizing the variance across the total range of scores. For 25 words per passage, the range from 0 to 100% correct is transformed to -13.8 to 113.8 rau.

Analysis of variance for repeated measures within subjects was used to determine: 1) the amount and significance of enhancement of speechreading provided by cochlear implant use (AV vs. V) and whether this enhancement was significant, and 2) the amount and significance of synergistic benefit from simultaneous use of auditory and visual cues compared with auditory and visual cues each presented alone. This analysis was done for individual subjects and the group.

Score variability estimates were determined in the following manner. The passage-to-passage variability for a single passage was estimated using the within-cells sums of squares from both the Between-Subjects effects and the set Within-Subject effect:

$$SD_{Passages} = \sqrt{\frac{SS_{within\ cells\ (from\ between\ subjects)} + SS_{within\ cells\ (from\ set)}}{}}$$

For a combined mean score on 6 passages (ie., one set), the variability of this mean from one set of 6 passages to another set of 6 passages is:

$$SD_{Sets} = \frac{SD_{Passages}}{\sqrt{6}}$$

The test-retest variability for a single passage is estimated using the sums of squares from the set and the within cells sums of squares for this:

$$SD_{\substack{Test/Retest \\ Single\ Passage}} = \sqrt{\frac{SS_{Set} + SS_{\substack{Within\ cells \\ (within\ subject)}}}{6}}$$

If 6 passages are used in a set, the test-retest variability (standard error of measurement) for the mean across 6 passages would be predicted to be:

$$SD_{\substack{Test/Retest \\ Sets}} = \frac{SD_{\substack{Test/Retest \\ (Single\ Passage)}}}{\sqrt{6}}$$

These four estimates of variability ($SD_{Passages}$, SD_{Sets}, $SD_{Test/Retest\ Single\ Passages}$, and $SD_{Test/Retest\ Single\ Set}$) were calculated for individual subjects and the group.

Only the data from the first four sessions of data collection with the test passages were used for the statistical analysis described above. The reason the data from the last four sessions were omitted from this analysis was because of the strong effect of prior experience (particularly the AV condition) on the responses during testing with the same passages in another condition.

RESULTS

Practice Passages

The word scores (rau) for each passage and condition on each of the three days of practice are shown in Figures 1 through 5. For most subjects in all three conditions, there was some improvement in scores from presentation of the first passage to subsequent presentations in the same condition.

Test Passages

Passage and Set Scores

The scores for the group for each passage and the mean across six passages (that is, the set score) and one standard error of the mean are shown in Table 5 (similar tables for each subject are included in Appendix B). The scores are shown for each condition (audition+vision, vision-only and audition-only) as a function of testing order.

The passages given in the first set (passage order from 1 to 6) and the passages given in the second set (passage order from 7 to 12) represent the test-retest of the same set of topic passages for each of the conditions. For the group, the set-retest score for the audition+vision condition increased 3.5 rau, for the vision-only condition it increased 5.6 rau, and for the audition-only condition it increased 3.6 rau.

The passages given in the third and fourth sets (passage order from 13 through 24) are shown in the bottom half of Table 5. For the group, the third and fourth set scores for the audition+vision condition (69.1 and 71.3 rau) are lower than first set score (77.4); the passages included in the third and fourth

sets may have been more difficult than those in the first set.

For the vision-only condition, the first set score for the group was 18.3 rau, whereas the third and fourth set scores were 28.6 and 39.8 rau. This improvement of 10 to 20 rau is probably related to having prior experience with the same passages in the audition+vision condition. There was a similar improvement, probably for the same reason, in the audition-only condition. In this condition, the first set score was 18.1, whereas the third and fourth set scores were 37.8 and 35.3 rau.

It appears that prior experience in the vision-only and audition-only conditions does not seem to be associated with improved scores in the audition+vision condition. However, prior experience in the audition+vision condition (for which the subjects understood 63 to 90% of the words correct in the first set) gave these subjects additional information with which to guess in the vision-only and audition-only conditions. Although this result is an important indication of the effect of prior experience on the test scores, it makes it impossible to use the data from the third and fourth sets in the statistical analysis (ANOVA) of score variability and benefit provided by the implant.

Score Variability

Test-Retest Variability. The mean scores (rau) for testing and retesting the same set of six passages (with a different set of topics for each of the conditions: audition-plus-vision, vision-only and audition-only) are shown for individual subjects and the group in Figure 6. In only two instances (subject 3, audition-plus-vision; subject 4, audition only), were the scores on the second set less than those on the first set. As described above, group means were 3.5, 5.6 and 3.7 rau higher on the retest set for the audition-plus-vision, vision-only, and audition-only conditions, respectively. Subject 2 in the audition-plus-vision and audition-only conditions, and subject 3 in the vision-only condition, showed the largest improvement in set score from test to retest.

Statistical analysis of the test-retest variability for single passages and entire sets, for all three conditions, is displayed in Table 6. The standard error of measurement for a single-passage score in the audition-plus-vision condition ranges from 4.6 to 12.4 rau for individual subjects. In the vision-only condition, these scores range from 5.0 to 11.7 rau. And in the audition-only condition, these scores range from 6.5 to 16.0 rau. For the group, the standard error of measurement for single-passage scores is 9.1, 7.6 and 9.5 rau for the audition-plus-vision, vision-only and audition-only conditions, respectively.

The standard error of measurement for a single set (of six passages) score in the audition-plus-vision condition range from 1.9 to 5.1 rau for individual subjects. In the vision-only

condition, these scores range from 2.0 to 4.8 rau, and with the audition only condition, from 2.6 to 6.5 rau. For the group, the standard error of measurement for a single-set score is 3.7, 3.1 and 3.9 rau for audition-plus-vision, vision-only and audition-only, respectively.

Passage to Passage, Set to Set Variability. The passage-to-passage and set-to-set variability for the three conditions (audition-plus-vision, vision-only and audition-only) was estimated for single subjects and the group. As described above, the standard error of measurement was calculated; these scores are displayed in Table 7.

The standard error of measurement for a passage-to-passage score for the audition-plus-vision condition ranged from 12.4 to 14.5 rau for individual subjects. In the vision-only condition, these scores ranged from 8.6 to 15.4 rau and in the audition-only condition, from 6.5 to 14.4 rau. For the group, the standard error of measurement is 13.3, 12.1 and 13.2 rau for the audition-plus-vision, vision-only and audition-only conditions, respectively.

The standard error of measurement for a set-to-set score for the audition-plus-vision condition ranged from 5.1 to 5.9 rau for individual subjects. In the vision-only condition, these scores ranged from 3.5 to 6.3 rau and in the audition-only condition, from 2.6 to 8.6 rau. For the group, the standard error of measurement is 5.4, 4.9 and 5.4 rau for the audition-plus-vision, vision-only and audition-only conditions, respectively.

The 95% critical difference for two scores (each based on a

different set of six passages) is 30.0 rau for the audition-plus-vision condition, 27.2 rau for the vision-only condition and 30.0 rau for the audition-only condition. These values for each condition were calculated by multiplying the Set-to-Set value for "all" subjects in Table 7 by 2(1.96* 2). The 95% critical difference for two scores (each based on the same set of six passages presented two weeks apart) is 20.5 rau for the audition-plus-vision condition, 17.2 rau for the vision-only condition and 21.6 rau for the audition-only condition. These values for each condition were calculated by multiplying the Set-to-Set value for "all" subjects in Table 6 by 2(1.96* 2).

Enhancement of Speechreading by Cochlear Implant Use

The mean scores (rau) for the audition-plus-vision and vision-only conditions are shown for each subject and the group for sessions 1, 2, 3, and 4 in Figure 7. During these sessions, 12 passages were presented for each of the two conditions. These passage and set scores are shown for the group in Table 5 and for individual subjects in Appendix B. For the group, enhancement of speechreading by implant use (audition-plus-vision mean score minus vision-only mean score) was 58.1 rau, and for subjects 1 through 5, this enhancement was 60.4, 65.3, 78.3, 57.5 and 28.7 rau, respectively. Enhancement of speechreading by implant use was highly significant for the group and each of the subjects as shown in Table 8.

As part of this statistical analysis (ANOVA), it was determined that the scores for subjects 1, 3, 4 and 5 were not significantly different between the first set of six passages and

the second set of six passages. For subject 2 and the group, there was a statistically significant improvement in score for the second set of six passages ([F(1,10)=8.35,p=0.016] and [F(1,50)=5.54,p=0.023], respectively). There were no significant interactions between condition and set for individual subjects or the group; there were no interactions between subject and set, or between condition, subject and set for the group.

Synergistic Benefit from Simultaneous Auditory and Visual Cues

The mean scores (percent correct) for the audition-plus-vision condition are shown in relation to the mean scores for the audition-only and vision-only conditions for each subject and the group for sessions 1, 2, 3 and 4 in Figure 8. During these sessions, 12 passages were presented for each of the three conditions. These passage and set scores are shown for the group in Table 5 and for individual subjects in Appendix B. The synergistic benefit from simultaneous auditory and visual cues (audition-plus-vision mean score minus the sum of the vision-only and audition-only mean scores) is highly significant for individual subjects as well as the group as shown in Table 9.

As part of this statistical analysis (ANOVA), it was determined that the scores for subjects 1, 3, 4 and 5 on the first set of six passages were not significantly different from their scores on the second set of six passages. For subject 2 and the group, there was a statistically significant improvement in score for the second set of six passages ([F(1,10)=28.30, p<0.001] and [F(1,58)=7.24,p=0.009], respectively). There were no significant interactions between condition and set for sub-

jects 1, 2, 4 and 5 as well as the group. For subject 3, this interaction was significant at the 0.005 level.

DISCUSSION

In the present study, the amount of enhancement of speechreading by cochlear implant use (audition-plus-vision mean score minus vision-only mean score), was highly significant for the group (58.1 rau) and for each of the five subjects (the scores were 60.4, 65.3, 78.3, 57.5 and 28.7 rau for subjects 1 through 5, respectively). That is, the implant provided an average increase in score of approximately 58% over speechreading alone for these five subjects.

The synergistic benefit from receiving simultaneous auditory and visual cues (audition-plus-vision mean score minus the sum of the vision-only and audition-only mean score) was highly significant for individual subjects and the group.

The 95% critical difference for two scores (each based on a different set of six passages) for audition-plus-vision, vision-only and audition-only conditions in this study is more than double the 95% critical difference for two scores in the study by Cox et al. (1989). In the present study, this critical difference was approximately 30.0 rau in all three conditions where as it was 12.2 rau for hearing-impaired listeners in the Cox et al. study. Possible reasons for the larger variability in the present study are the presentation of only 18 of the 48 test passages, the small number of subjects, the use of a cochlear implant to deliver auditory information, and the presentation of the CST in quiet instead of mixed with babble. Only five sub-

jects were included in the present study and sixty-three hearing-impaired subjects were included in the second study by Cox et al. (1988). In addition, the Nucleus Cochlear Implant System extracts information from a 30-dB range of incoming sound whereas the linear amplification system used by Cox et al. provided subjects with the full analog waveform of the speech. Finally, the CST was presented in quiet in the present study whereas it was presented at signal-to-babble ratios between 7 and 0 dB in the Cox et al. study.

One of the reasons for evaluating cochlear implant patients with the Connected Speech Test (Version 3) in this study was to determine whether the scores would be lower than those obtained with the CID Everyday Sentences in the audition-plus-vision testing condition. As part of another study (Holden and Skinner, unpublished), the Johns Hopkins recording of the CID sentences was presented to the five subjects in the present study. Their scores in the audition-plus-vision condition ranged from 92.4 to 106.9 rau (89.8 to 97.3% correct); these scores demonstrate a ceiling effect. In contrast, the CST scores ranged from 66.2 to 97.6 rau (67.2 to 93% correct). Each subjects' scores on the two tests are shown in Figure 9. The scores for both the CSTv3 and the CID Everyday Sentences were based on 300 key words identified by each of the subjects. For all except subject 2, use of the CST eliminated the ceiling effect; subject 2's performance was above average.

In summary, the CST laser video disc recording (Cox et al., 1989) provides more difficult material than the CID Everyday

Sentences recordings (Bernstein and Eberhardt, 1986; Davis and Silverman, 1978) for evaluating the performance of post linguistically deaf cochlear implant patients who have the ability to recognize a substantial number of words (open-set) by sound alone. The CST is an important addition to the test available for evaluating the enhancement of speechreading by cochlear implant use.

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Table 1. Subject information.

Sex	Male	Male	Male	Male	Female
Age when implanted (years)	60	44	61	61	45
Years of profound deafness	17	4	10	4	22
Etiology	Oto-sclero-sis	Auto-immune disease	Oto-sclero-sis	Noise trauma; prog-ressive hearing loss	Severe Pro-gress-ive hearing loss
Implanted ear	Left	Left	Right	Left	Right
Depth, electrode insertion (mm)	25	23	25	25	25
Number of electrode pairs	19	18	20	20	18
Electrodes elimin-ated	17	1,3			3,5
Months of implant experience	20	19	14	12	0.5

Table 2. Topic words for each Connected Speech Test (version 2) passage pair and designated sets of four and six passages comprising the Connected Speech Test, version 3 (from Cox et al., 1989).

Passage Pair	Sets 4	Sets 6	Passage Pair	Sets 4	Sets 6
window/glove			cabbage/gold		
umbrella/giraffe			weed/chimney		
lung/dove			lead/calendar		
carrot/grass			lion/zebra		
nail/woodpecker			lizard/wolf		
owl/vegetable			orange/oyster		
lemon/violin			dice/eagle		
wheat/ice			ear/liver		
donkey/guitar			leopard/eye		
envelope/grasshopper			zipper/egg		
lettuce/dictionary			clock/kangaroo		
lawn/cactus			camel/goose		

Table 3. A passage on the topic, "Carrot," from the Connected Speech Test version 3 (Cox et al., 1989) with the key words shown in bold type.

1. A carrot is a **vegetable related** to parsley.
2. The **long** stem of the carrot **grows underground.**
3. It is **this stem** that most people **eat.**
4. The **leaves** of the **carrot** are also eaten.
5. They are often used to **flavor** foods.
6. Spring **crops** are **grown** in the western **states.**
7. The crop is **harvested** in **one hundred** days.
8. Fall crops **are grown** in the **northern states.**
9. Winter **harvests** usually come from **California.**
10. **Winter** crops are also **grown** in **Texas.**

Table 4. Conditions (audition+vision: AV; vision-only: V; audition-only: A) in which five cochlear implant subjects were evaluated with the Connected Speech Test Version 3. Although the sequence of passages was identical for the five subjects for sessions 1 through 4, different pseudorandomizations were used for each subject for sessions 5 through 8. This table was for subject 2.

Session 1 & 3	
Passage	Condition
62	AV
7	AV
13	V
19	A
8	AV
14	V
20	A
9	AV
15	V
21	A

Session 5	
Passage	Condition
49	AV
16	AV
23	V
9	A
14	AV
22	V
11	A
18	AV
24	V
7	A

Session 7	
Passage	Condition
57	AV
24	AV
8	V
16	A
19	AV
12	V
18	A
22	AV
11	V
14	A

Session 2 & 4	
Passage	Condition
51	AV
10	AV
16	V
22	A
11	AV
17	V
23	A
12	AV
18	V
24	A

Session 6	
Passage	Condition
56	AV
15	AV
21	V
12	A
13	AV
20	V
8	A
17	AV
19	V
10	A

Session 8	
Passage	Condition
60	AV
20	AV
9	V
17	A
23	AV
7	V
13	A
21	AV
10	V
15	A

Table 5. The passage scores expressed as raw scores (RAW: # of words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) averaged across the five subjects as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	21.4	85.6%	86.9	6.4	25.6%	25.8	7.7	30.8%	31.6
2	18.3	73.2%	73.5	5.2	20.8%	20.1	2.6	10.4%	7.8
3	21.1	84.4%	85.6	2.9	11.6%	8.1	2.9	11.6%	6.2
4	17.4	69.6%	68.4	8.8	35.2%	33.9	5.5	22.0%	21.1
5	16.7	66.8%	65.9	4.2	16.8%	14.9	5.8	23.2%	22.5
6	21.0	84.0%	84.0	3.1	12.4%	7.0	5.2	20.8%	19.4
Set x	19.3	77.3%	77.4	5.1	20.4%	18.3	5.0	19.8%	18.1
SE	0.67	2.67%	2.93	0.82	3.29%	3.86	0.77	3.09%	3.59
7	22.4	89.6%	91.4	6.8	27.2%	27.4	8.5	34.0%	32.8
8	19.0	76.0%	77.8	6.0	24.0%	24.7	4.6	18.4%	15.8
9	21.0	84.0%	86.5	5.1	20.4%	19.3	3.4	13.6%	9.6
10	18.8	75.2%	74.3	9.2	36.8%	37.3	6.8	27.2%	27.3
11	18.1	72.4%	74.1	5.2	20.8%	19.7	7.2	28.8%	25.6
12	20.3	81.2%	81.6	4.4	17.6%	15.1	5.6	22.4%	19.6
Set x	19.9	79.7%	80.9	6.1	24.5%	23.9	6.0	24.1%	21.8
SE	0.63	2.51%	3.18	0.80	3.21%	3.48	1.07	4.30%	4.72
13	18.9	75.6%	76.6	6.2	24.8%	25.8	8.7	34.8%	34.6
14	14.2	56.8%	58.0	7.0	28.0%	26.8	9.8	39.2%	39.4
15	17.3	69.2%	68.2	9.1	36.4%	36.1	9.6	38.4%	37.8
16	17.7	70.8%	72.7	7.3	29.2%	29.3	8.8	35.2%	35.7
17	16.5	66.0%	66.5	7.1	28.4%	28.0	9.8	39.2%	39.5
18	18.3	73.2%	72.6	6.8	27.2%	25.3	9.8	39.2%	40.0
Set x	17.2	68.6%	69.1	7.3	29.0%	28.6	9.4	37.7%	37.8
SE	0.85	3.38%	3.70	0.99	3.94%	4.04	1.26	5.02%	5.04
19	17.3	69.2%	68.0	8.6	34.4%	33.3	8.4	33.6%	31.2
20	20.6	82.4%	82.3	9.7	38.8%	39.1	8.8	35.2%	34.5
21	16.1	64.4%	63.2	9.2	36.8%	37.2	8.3	33.2%	33.2
22	19.1	76.4%	78.6	11.6	46.4%	46.0	9.1	36.4%	33.9
23	15.2	60.8%	61.8	9.0	36.0%	35.9	9.0	36.0%	35.4
24	18.8	75.2%	74.1	11.9	47.6%	47.2	10.8	43.2%	43.5
Set x	17.9	71.4%	71.3	10.0	40.0%	39.8	9.1	36.3%	35.3
SE	0.77	3.09%	3.29	0.91	3.65%	3.66	1.10	4.39%	4.66

Table 6. Standard error of measurement (rau) of test-retest scores, in rationalized arcsine units (rau) for single passages and single sets for each subject and the group in the audition-plus-vision (AV), vision-only (V) and audition-only (A) conditions.

	Subjects					
	1	2	3	4	5	ALL
AV						
Single Passage Test-Retest	11.7	10.3	4.6	12.4	6.4	9.1
Set Test-Retest	4.8	4.2	1.9	5.1	2.6	3.7
V						
Single Passage Test-Retest	5.0	6.9	11.7	6.2	8.4	7.6
Set Test-Retest	2.0	2.8	4.8	2.5	3.4	3.1
A						
Single Passage Test-Retest	6.5	16.0	7.4	9.4	8.2	9.5
Set Test-Retest	2.6	6.5	3.0	3.8	3.3	3.9

Table 7. Standard error of measurement (rau) of passage-to-passage and set-to-set scores for individual subjects and the group in the audition-plus-vision (AV), vision-only (V) and audition-only (A) conditions.

	Subjects					
	1	2	3	4	5	ALL
AV						
Passage-to-Passage	14.5	12.4	13.9	13.0	12.5	13.3
Set-to-Set	5.9	5.1	5.7	5.3	5.1	5.4
V						
Passage-to-Passage	12.6	14.9	9.0	15.4	8.6	12.1
Set-to-Set	5.2	6.1	3.7	6.3	3.5	4.9
A						
Passage-to-Passage	6.5	13.9	21.1	10.3	14.4	13.2
Set-to-Set	2.6	5.7	8.6	4.2	5.9	5.4

Table 8. ANOVA values (degrees of freedom: df; mean sums of squares: MS; F-ratio; statistical significance) for repeated measures within subjects obtained during analysis of the difference between scores (rau) on the CST for the audition-plus-vision condition versus the vision-only condition.

Subject	df	MS	F-ratio	Statistical Significance
1	10	14.03		
	1	1372.59	97.85	p<0.001
2	10	17.52		
	1	1380.17	78.79	p<0.001
3	10	10.20		
	1	2044.26	200.38	p<0.001
4	10	12.65		
	1	1155.01	91.30	p<0.001
5	10	8.54		
	1	333.76	39.10	p<0.001
ALL	50	12.59		
	1	5894.01	468.27	p<0.001

Table 9. ANOVA values (degrees of freedom: df; mean sums of squares: MS; F-ratio; statistical significance) for repeated measures within subjects obtained during analysis of the difference between scores (rau) on the CST for the audition-plus-vision condition versus the sum of the vision-only and audition-only conditions.

Subject	df	MS	F-ratio	Statistical Significance
1	10	178.85		
	1	25434.57	142.21	p<0.001
2	10	171.59		
	1	19912.32	116.04	p<0.001
3	10	352.70		
	1	23064.00	65.39	p<0.001
4	10	210.21		
	1	23418.75	111.41	p<0.001
5	10	193.62		
	1	11063.92	57.14	p<0.001
ALL	50	501.05		
	1	101012.82	201.60	p<0.001

APPENDIX A: List of passages and conditions as a function of session number for subjects 1, 3, 4 and 5.

Table A1. Conditions (audition+vision: AV; vision-only: V; audition-only: A) in which subject 1 was evaluated with the Connected Speech Test Version 3 during sessions 5 through 8.

Session 5		Session 6	
Passage	Condition	Passage	Condition
49	AV	56	AV
13	AV	14	AV
19	V	22	V
12	A	11	A
17	AV	18	AV
24	V	23	V
9	A	10	A
15	AV	16	AV
21	V	20	V
8	A	7	A

Session 7		Session 8	
Passage	Condition	Passage	Condition
57	AV	60	AV
21	AV	19	AV
10	V	11	V
18	A	13	A
20	AV	24	AV
8	V	9	V
16	A	15	A
23	AV	22	AV
7	V	12	V
17	A	14	A

Table A2. Conditions (audition+vision: AV; vision-only: V; audition-only: A) in which subject 3 was evaluated with the Connected Speech Test Version 3 during sessions 5 through 8.

Session 5	
Passage	Condition
49	AV
22	AV
9	V
17	A
21	AV
7	V
16	A
23	AV
11	V
13	A

Session 6	
Passage	Condition
56	AV
20	AV
12	V
15	A
24	AV
10	V
14	A
19	AV
8	V
18	A

Session 7	
Passage	Condition
57	AV
16	AV
22	V
11	A
15	AV
24	V
7	A
14	AV
23	V
8	A

Session 8	
Passage	Condition
60	AV
18	AV
20	V
9	A
17	AV
19	V
12	A
13	AV
21	V
10	A

Table A3. Conditions (audition+vision: AV; vision-only: V; audition-only: A) in which subject 4 was evaluated with the Connected Speech Test Version 3 during sessions 5 through 8.

Session 5

Passage	Condition
49	AV
14	AV
22	V
11	A
18	AV
20	V
10	A
16	AV
23	V
9	A

Session 6

Passage	Condition
56	AV
17	AV
24	V
7	A
15	AV
19	V
12	A
13	AV
21	V
8	A

Session 7

Passage	Condition
57	AV
20	AV
11	V
14	A
23	AV
7	V
13	A
24	AV
8	V
15	A

Session 8

Passage	Condition
60	AV
22	AV
12	V
18	A
21	AV
10	V
16	A
19	AV
9	V
17	A

Table A4. Conditions (audition+vision: AV; vision-only: V; audition-only: A) in which subject 5 was evaluated with the Connected Speech Test Version 3 during sessions 5 through 8.

Session 5

Passage	Condition
49	AV
21	AV
10	V
14	A
24	AV
7	V
17	A
20	AV
12	V
15	A

Session 6

Passage	Condition
56	AV
19	AV
9	V
18	A
23	AV
11	V
16	A
22	AV
8	V
13	A

Session 7

Passage	Condition
57	AV
17	AV
20	V
8	A
14	AV
22	V
11	A
18	AV
24	V
9	A

Session 8

Passage	Condition
60	AV
15	AV
23	V
10	A
13	AV
21	V
7	A
16	AV
19	V
12	A

APPENDIX B: Passage and set scores for subjects 1 through 5.

Table B1. The passage scores expressed as raw scores (RAW: # words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) for subject 1 as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	21.5	86.0%	85.6	2.0	8.0%	6.2	3.0	12.0%	11.8
2	18.5	74.0%	72.3	4.0	16.0%	16.8	1.0	4.0%	-0.8
3	22.0	88.0%	88.2	1.0	4.0%	-0.8	2.0	8.0%	6.2
4	15.0	60.0%	59.0	9.5	38.0%	39.2	1.0	4.0%	-0.8
5	16.0	64.0%	62.7	4.0	16.0%	16.8	2.0	8.0%	6.2
6	21.0	84.0%	83.2	2.0	8.0%	6.2	1.0	4.0%	-0.8
Set x	19.0	76.0%	75.2	3.8	15.0%	14.1	1.7	6.7%	3.6
SE	1.22	4.87%	5.06	1.25	5.00%	5.75	0.33	1.33%	2.15
7	22.0	88.0%	88.2	5.0	20.0%	21.4	2.0	8.0%	6.2
8	13.0	52.0%	51.8	4.0	16.0%	16.8	1.0	4.0%	-0.8
9	23.0	92.0%	93.8	2.0	8.0%	6.2	3.0	12.0%	11.8
10	22.0	88.0%	88.2	8.5	34.0%	35.5	3.0	12.0%	11.8
11	18.0	72.0%	70.3	3.5	14.0%	14.4	5.0	20.0%	21.4
12	17.0	68.0%	66.4	2.0	8.0%	6.2	2.0	8.0%	6.2
Set x	19.2	76.7%	76.5	4.2	16.7%	16.7	2.7	10.7%	9.4
SE	1.58	6.32%	6.64	0.99	3.96%	4.48	0.56	2.23%	3.05
13	20.0	80.0%	78.6	4.0	16.0%	16.8	1.0	4.0%	-0.8
14	11.5	46.0%	46.4	10.0	40.0%	41.0	5.0	20.0%	21.4
15	11.5	46.0%	46.4	6.0	24.0%	25.6	3.0	12.0%	11.8
16	17.0	68.0%	66.4	2.5	10.0%	9.1	4.0	16.0%	16.8
17	10.0	40.0%	41.0	7.0	28.0%	29.7	1.0	4.0%	-0.8
18	16.0	64.0%	62.7	4.0	16.0%	16.8	6.0	24.0%	25.6
Set x	14.3	57.3%	56.9	5.6	22.3%	23.2	3.3	13.3%	12.4
SE	1.60	6.40%	5.97	1.10	4.39%	4.63	0.84	3.37%	4.56
19	12.0	48.0%	48.2	1.0	4.0%	-0.8	5.0	20.0%	21.4
20	20.0	80.0%	78.6	12.0	48.0%	48.2	2.5	10.0%	9.1
21	16.0	64.0%	62.7	7.5	30.0%	31.6	4.0	16.0%	16.8
22	21.0	84.0%	83.2	13.0	52.0%	51.8	3.0	12.0%	11.8
23	11.0	44.0%	44.6	10.0	40.0%	41.0	2.0	8.0%	6.2
24	16.0	64.0%	62.7	12.0	48.0%	48.2	6.0	24.0%	25.6
Set x	16.0	64.0%	63.3	9.3	37.0%	36.7	3.8	15.0%	15.2
SE	1.65	6.61%	6.34	1.83	7.33%	8.04	0.63	2.52%	3.05

Table B2. The passage scores expressed as raw scores (RAW: # words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) for subject 2 as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	24.0	96.0%	100.8	9.0	36.0%	37.3	12.5	50.0%	50.0
2	24.0	96.0%	100.8	8.0	32.0%	33.6	7.0	28.0%	29.7
3	24.5	98.0%	105.3	3.0	12.0%	11.8	8.5	34.0%	35.5
4	19.0	76.0%	74.4	15.0	60.0%	59.0	4.0	16.0%	16.8
5	21.0	84.0%	83.2	4.5	18.0%	19.2	11.0	44.0%	44.6
6	23.0	92.0%	93.8	4.5	18.0%	19.2	13.0	52.0%	51.8
Set x	22.6	90.3%	93.0	7.3	29.3%	30.0	9.3	37.3%	38.1
SE	0.88	3.52%	4.88	1.80	7.19%	7.01	1.42	5.70%	5.48
7	24.5	98.0%	105.3	8.0	32.0%	33.6	20.5	82.0%	80.8
8	25.0	100.0%	113.8	8.0	32.0%	33.6	16.0	64.0%	62.7
9	25.0	100.0%	113.8	6.0	24.0%	25.6	11.0	44.0%	44.6
10	21.0	84.0%	83.2	15.5	62.0%	60.8	10.0	40.0%	41.0
11	25.0	100.0%	113.8	8.0	32.0%	33.6	16.0	64.0%	62.7
12	23.0	92.0%	93.8	7.5	30.0%	31.6	15.0	60.0%	59.0
Set x	23.9	95.7%	104.0	8.8	35.3%	36.5	14.8	59.0%	58.5
SE	0.66	2.65%	5.26	1.37	5.48%	5.03	1.56	6.23%	5.87
13	24.0	96.0%	100.8	10.0	40.0%	41.0	21.0	84.0%	83.2
14	23.5	94.0%	97.1	15.0	60.0%	59.0	21.0	84.0%	83.2
15	25.0	100.0%	113.8	9.5	38.0%	39.2	23.0	92.0%	93.8
16	24.0	96.0%	100.8	8.0	32.0%	33.6	20.0	80.0%	78.6
17	20.0	80.0%	78.6	11.5	46.0%	46.4	22.0	88.0%	88.2
18	24.5	98.0%	105.3	8.0	32.0%	33.6	19.5	78.0%	76.5
Set x	23.5	94.0%	99.4	10.3	41.3%	42.1	21.1	84.3%	83.9
SE	0.73	2.92%	4.77	1.08	4.31%	3.92	0.52	2.09%	2.59
19	19.0	76.0%	74.4	18.5	74.0%	72.3	13.0	52.0%	51.8
20	25.0	100.0%	113.8	14.0	56.0%	55.4	17.0	68.0%	66.4
21	24.0	96.0%	100.8	17.0	68.0%	66.4	13.5	54.0%	53.6
22	23.0	92.0%	93.8	11.5	46.0%	46.4	15.0	60.0%	59.0
23	20.5	82.0%	80.8	16.0	64.0%	62.7	18.5	74.0%	72.3
24	19.0	76.0%	74.4	14.0	56.0%	55.4	16.0	64.0%	62.7
Set x	21.8	87.0%	89.7	15.2	60.7%	59.8	15.5	62.0%	61.0
SE	1.06	4.25%	6.51	1.02	4.09%	3.77	0.86	3.43%	3.19

Table B3. The passage scores expressed as raw scores (RAW: # words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) for subject 3 as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	24.0	96.0%	100.8	4.0	16.0%	16.8	10.0	40.0%	41.0
2	21.0	84.0%	83.2	1.0	4.0%	-0.8	1.0	4.0%	-0.8
3	23.0	92.0%	93.8	0.0	0.0%	-13.8	4.0	16.0%	16.8
4	21.0	84.0%	83.2	0.5	2.0%	-5.3	13.5	54.0%	53.6
5	16.0	64.0%	62.7	1.0	4.0%	-0.8	10.0	40.0%	41.0
6	20.0	80.0%	78.6	0.0	0.0%	-13.8	8.0	32.0%	33.6
Set x	20.8	83.3%	83.7	1.1	4.3%	-2.9	7.8	31.0%	30.9
SE	1.14	4.55%	5.36	0.61	2.44%	4.63	1.85	7.41%	8.01
7	23.5	94.0%	97.1	2.0	8.0%	6.2	12.0	48.0%	48.2
8	19.0	76.0%	74.4	3.0	12.0%	11.8	3.0	12.0%	11.8
9	22.0	88.0%	88.2	1.5	6.0%	2.9	1.0	4.0%	-0.8
10	19.5	78.0%	76.5	3.0	12.0%	11.8	13.0	52.0%	51.8
11	13.5	54.0%	53.6	1.0	4.0%	-0.8	13.0	52.0%	51.8
12	19.5	78.0%	76.5	3.5	14.0%	14.4	7.0	28.0%	29.7
Set x	19.5	78.0%	77.7	2.3	9.3%	7.7	8.2	32.7%	32.1
SE	1.40	5.59%	6.00	0.40	1.61%	2.42	2.17	8.67%	9.19
13	22.0	88.0%	88.2	2.0	8.0%	6.2	11.0	44.0%	44.6
14	14.0	56.0%	55.4	3.0	12.0%	11.8	22.0	88.0%	88.2
15	17.0	68.0%	66.4	3.0	12.0%	11.8	9.0	36.0%	37.3
16	16.0	64.0%	62.7	3.0	12.0%	11.8	8.0	32.0%	33.6
17	20.0	80.0%	78.6	3.0	12.0%	11.8	14.5	58.0%	57.2
18	17.0	68.0%	66.4	3.0	12.0%	11.8	13.5	54.0%	53.6
Set x	17.7	70.7%	69.6	2.8	11.3%	10.9	13.0	52.0%	52.4
SE	1.17	4.70%	4.82	0.17	0.67%	0.95	2.07	8.28%	8.05
19	9.5	38.0%	39.2	4.0	16.0%	16.8	12.0	48.0%	48.2
20	16.0	64.0%	62.7	1.0	4.0%	-0.8	14.0	56.0%	55.4
21	18.0	72.0%	70.3	1.5	6.0%	2.9	7.5	30.0%	31.6
22	19.0	76.0%	74.4	2.0	8.0%	6.2	16.0	64.0%	62.7
23	19.5	78.0%	76.5	4.0	16.0%	16.8	10.0	40.0%	41.0
24	22.0	88.0%	88.2	5.0	20.0%	21.4	10.0	40.0%	41.0
Set x	17.3	69.3%	68.5	2.9	11.7%	10.6	11.6	46.3%	46.7
SE	1.76	7.04%	6.79	0.66	2.65%	3.66	1.25	5.02%	4.56

Table B4. The passage scores expressed as raw scores (RAW: # words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) for subject 4 as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	20.5	82.0%	80.8	4.0	16.0%	16.8	5.0	20.0%	21.4
2	10.0	40.0%	41.0	2.0	8.0%	6.2	1.0	4.0%	-0.8
3	19.0	76.0%	74.4	3.0	12.0%	11.8	0.0	0.0%	-13.8
4	15.0	60.0%	59.0	5.0	20.0%	21.4	2.0	8.0%	6.2
5	11.5	46.0%	46.4	0.5	2.0%	-5.3	1.0	4.0%	-0.8
6	18.0	72.0%	70.3	0.0	0.0%	-13.8	2.0	8.0%	6.2
Set x	15.7	62.7%	62.0	2.4	9.7%	6.2	1.8	7.3%	3.1
SE	1.73	6.92%	6.51	0.80	3.20%	5.50	0.70	2.81%	4.72
7	20.5	82.0%	80.8	4.0	16.0%	16.8	1.0	4.0%	-0.8
8	20.0	80.0%	78.6	4.0	16.0%	16.8	1.0	4.0%	-0.8
9	18.0	72.0%	70.3	2.0	8.0%	6.2	0.0	0.0%	-13.8
10	14.0	56.0%	55.4	9.0	36.0%	37.3	2.0	8.0%	6.2
11	17.0	68.0%	66.4	1.5	6.0%	2.9	0.0	0.0%	-13.8
12	18.0	72.0%	70.3	0.0	0.0%	-13.8	0.0	0.0%	-13.8
Set x	17.9	71.7%	70.3	3.4	13.7%	11.0	0.7	2.7%	-6.1
SE	0.95	3.81%	3.73	1.28	5.12%	6.99	0.33	1.33%	3.59
13	16.0	64.0%	62.7	1.0	4.0%	-0.8	7.0	28.0%	29.7
14	12.5	50.0%	50.0	3.5	14.0%	14.4	2.0	8.0%	6.2
15	13.0	52.0%	51.8	1.0	4.0%	-0.8	4.0	16.0%	16.8
16	15.0	60.0%	59.0	4.5	18.0%	19.2	8.0	32.0%	33.6
17	9.0	36.0%	37.3	4.5	18.0%	19.2	3.0	12.0%	11.8
18	16.0	64.0%	62.7	1.0	4.0%	-0.8	3.0	12.0%	11.8
Set x	13.6	54.3%	53.9	2.6	10.3%	8.4	4.5	18.0%	18.3
SE	1.10	4.39%	3.98	0.72	2.89%	4.16	0.99	3.97%	4.45
19	7.0	28.0%	29.7	5.0	20.0%	21.4	0.0	0.0%	-13.8
20	19.0	76.0%	74.4	9.0	36.0%	37.3	3.0	12.0%	11.8
21	23.0	92.0%	93.8	8.0	32.0%	33.6	5.0	20.0%	21.4
22	17.0	68.0%	66.4	10.0	40.0%	41.0	2.0	8.0%	6.2
23	13.0	52.0%	51.8	14.0	56.0%	55.4	2.0	8.0%	6.2
24	10.0	40.0%	41.0	13.0	52.0%	51.8	0.0	0.0%	-13.8
Set x	14.8	59.3%	59.5	9.8	39.3%	40.1	2.0	8.0%	3.0
SE	2.43	9.71%	9.55	1.35	5.41%	5.07	0.77	3.10%	5.78

Table B5. The passage scores expressed as raw scores (RAW: # words correct out of 25), percent correct (% correct), and rationalized arcsine units (RAU) for subject 5 as a function of testing order.

	AV			V			A		
ORDER	RAW	% CORR	RAU	RAW	% CORR	RAU	RAW	% CORR	RAU
1	17.0	68.0%	66.4	13.0	52.0%	51.8	8.0	32.0%	33.6
2	18.0	72.0%	70.3	11.0	44.0%	44.6	3.0	12.0%	11.8
3	17.0	68.0%	66.4	7.5	30.0%	31.6	0.0	0.0%	-13.8
4	17.0	68.0%	66.4	14.0	56.0%	55.4	7.0	28.0%	29.7
5	19.0	76.0%	74.4	11.0	44.0%	44.6	5.0	20.0%	21.4
6	23.0	92.0%	93.8	9.0	36.0%	37.3	2.0	8.0%	6.2
Set x	18.5	74.0%	73.0	10.9	43.7%	44.2	4.2	16.7%	14.8
SE	0.96	3.83%	4.37	0.99	3.95%	3.60	1.25	5.00%	7.12
7	21.5	86.0%	85.6	15.0	60.0%	59.0	7.0	28.0%	29.7
8	18.0	72.0%	70.3	11.0	44.0%	44.6	2.0	8.0%	6.2
9	17.0	68.0%	66.4	14.0	56.0%	55.4	2.0	8.0%	6.2
10	17.5	70.0%	68.4	10.0	40.0%	41.0	6.0	24.0%	25.6
11	17.0	68.0%	66.4	12.0	48.0%	48.2	2.0	8.0%	6.2
12	24.0	96.0%	100.8	9.0	36.0%	37.3	4.0	16.0%	16.8
Set x	19.2	76.7%	76.3	11.8	47.3%	47.6	3.8	15.3%	15.1
SE	1.19	4.75%	5.71	0.95	3.78%	3.41	0.91	3.64%	4.34
13	20.0	80.0%	78.6	12.0	48.0%	48.2	10.0	40.0%	41.0
14	18.0	72.0%	70.3	15.0	60.0%	59.0	10.5	42.0%	42.8
15	19.5	78.0%	76.5	11.0	44.0%	44.6	12.0	48.0%	48.2
16	20.0	80.0%	78.6	11.5	46.0%	46.4	13.0	52.0%	51.8
17	16.5	66.0%	64.5	13.0	52.0%	51.8	7.0	28.0%	29.7
18	20.0	80.0%	78.6	15.0	60.0%	59.0	14.0	56.0%	55.4
Set x	19.0	76.0%	74.5	12.9	51.7%	51.5	11.1	44.3%	44.8
SE	0.59	2.37%	2.39	0.71	2.85%	2.56	1.02	4.08%	3.74
19	13.0	52.0%	51.8	7.0	28.0%	29.7	6.0	24.0%	25.6
20	21.0	84.0%	83.2	18.0	72.0%	70.3	8.0	32.0%	33.6
21	16.0	64.0%	62.7	14.5	58.0%	57.2	7.0	28.0%	29.7
22	18.0	72.0%	70.3	15.5	62.0%	60.8	5.0	20.0%	21.4
23	17.0	68.0%	66.4	16.0	64.0%	62.7	7.5	30.0%	31.6
24	17.0	68.0%	66.4	18.0	72.0%	70.3	6.0	24.0%	25.6
Set x	17.0	68.0%	66.8	14.8	59.3%	58.5	6.6	26.3%	27.9
SE	1.06	4.26%	4.18	1.67	6.67%	6.15	0.45	1.82%	1.84

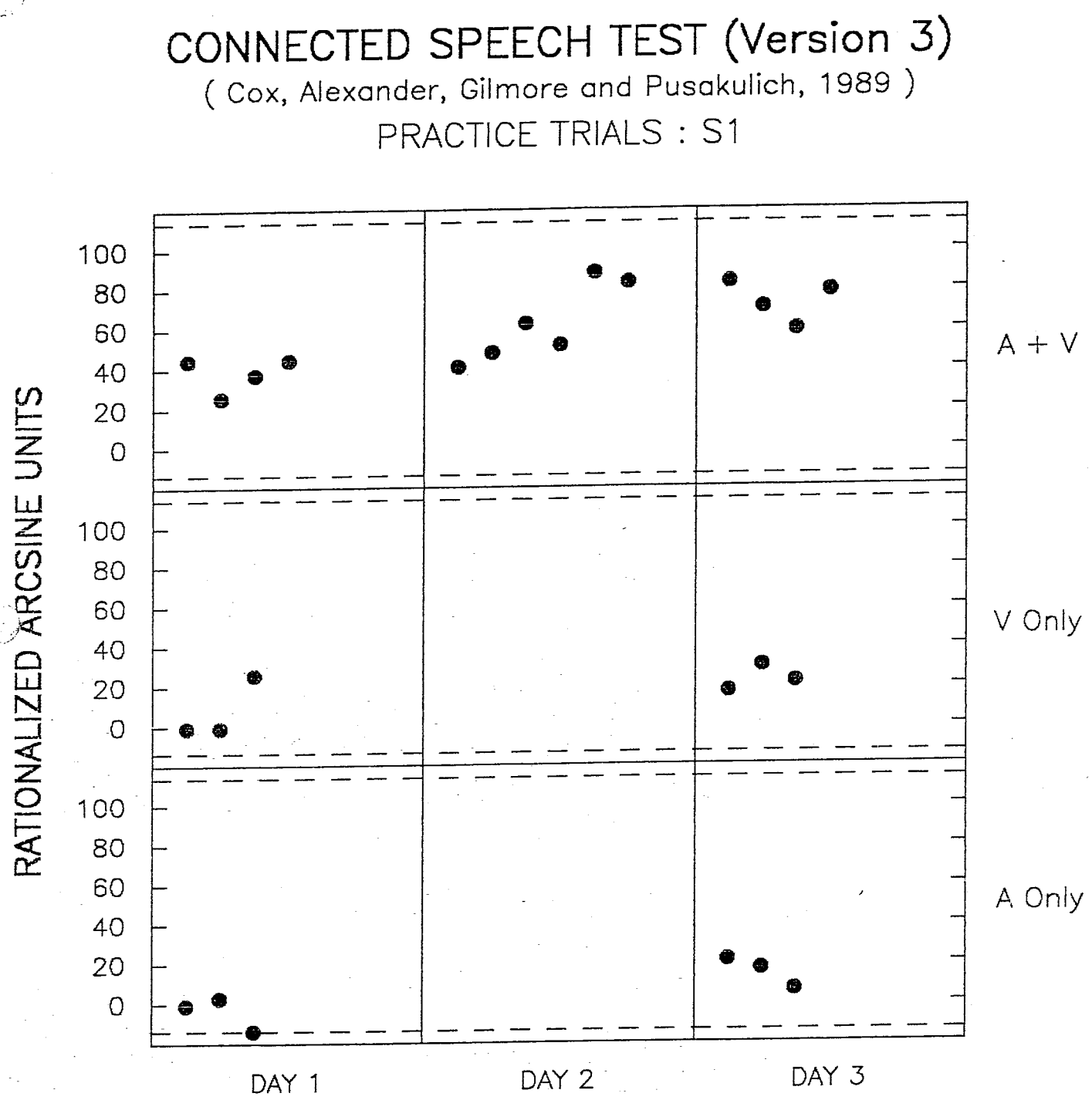

Figure 1. Individual passage scores (rau) on practice trials on the Connected Speech Test Version 3 for the three conditions (audition-plus-vision: A+V; vision only: V; audition only: A) for subject 1.

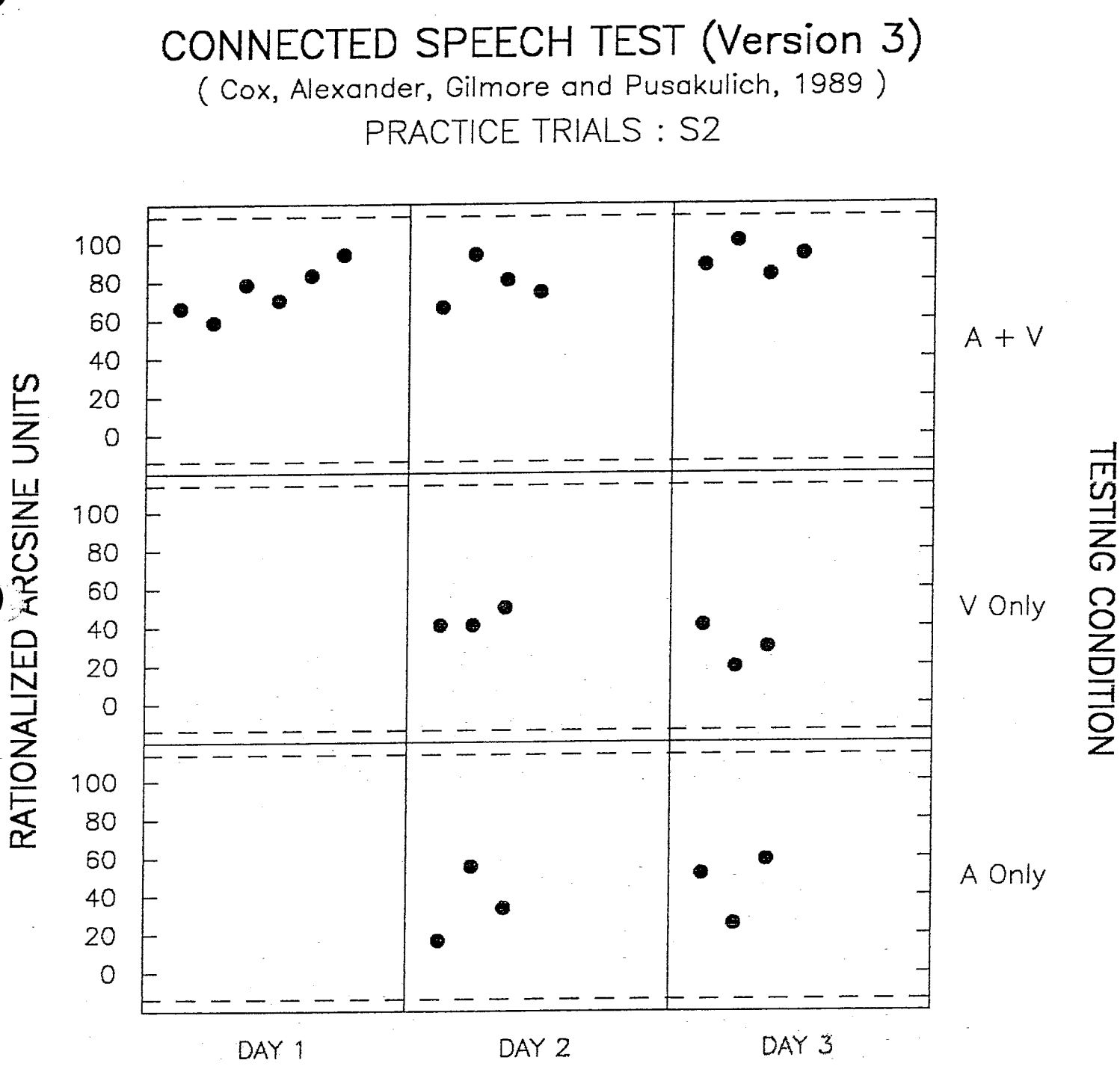

Figure 2. Individual passage scores (rau) on practice trials on the Connected Speech Test Version 3 for the three conditions (audition-plus-vision: A+V; vision only: V; audition only: A) for subject 2.

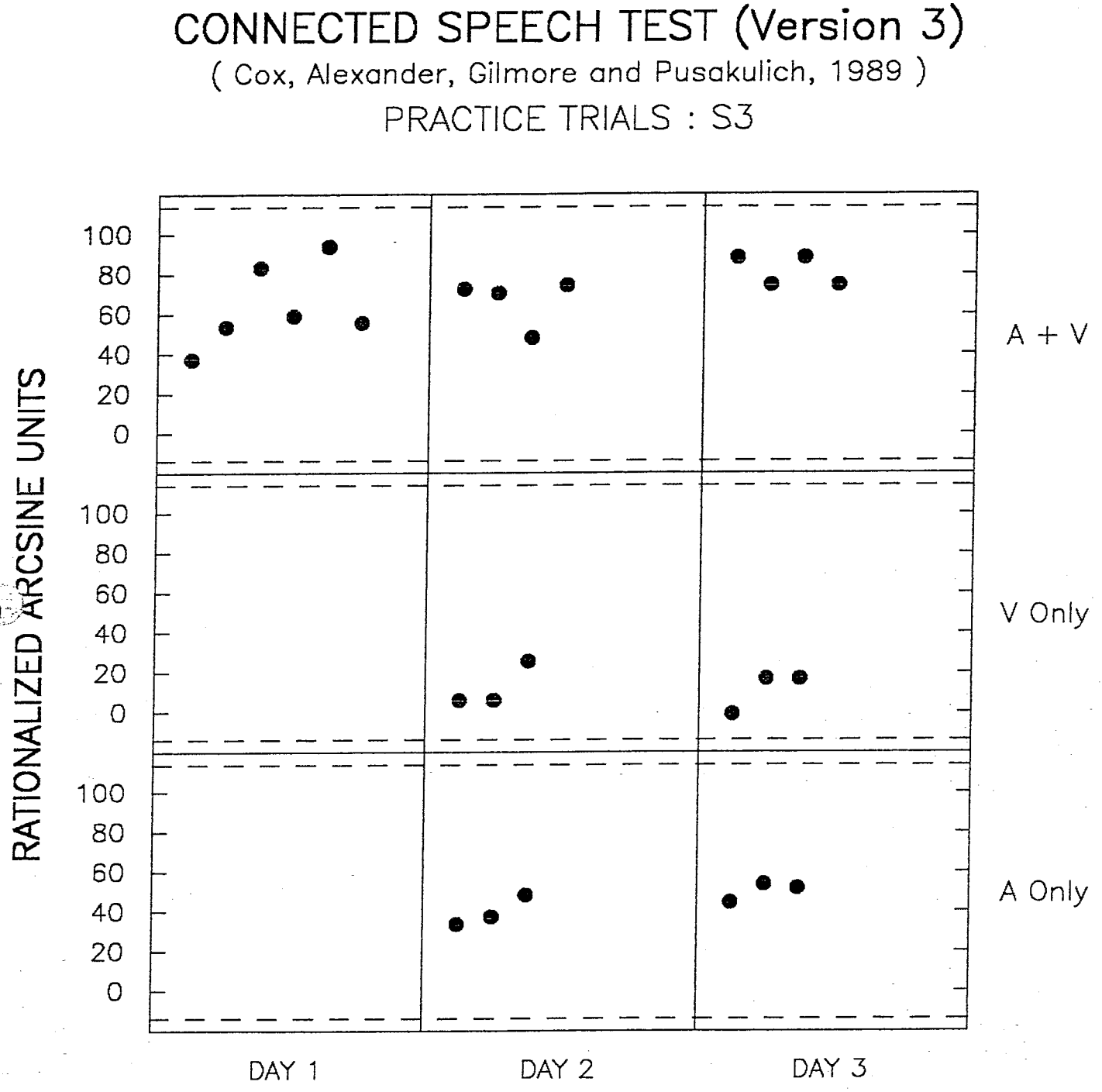

Figure 3. Individual passage scores (rau) on practice trials on the Connected Speech Test Version 3 for the three conditions (audition-plus-vision: A+V; vision only: V; audition only: A) for subject 3.

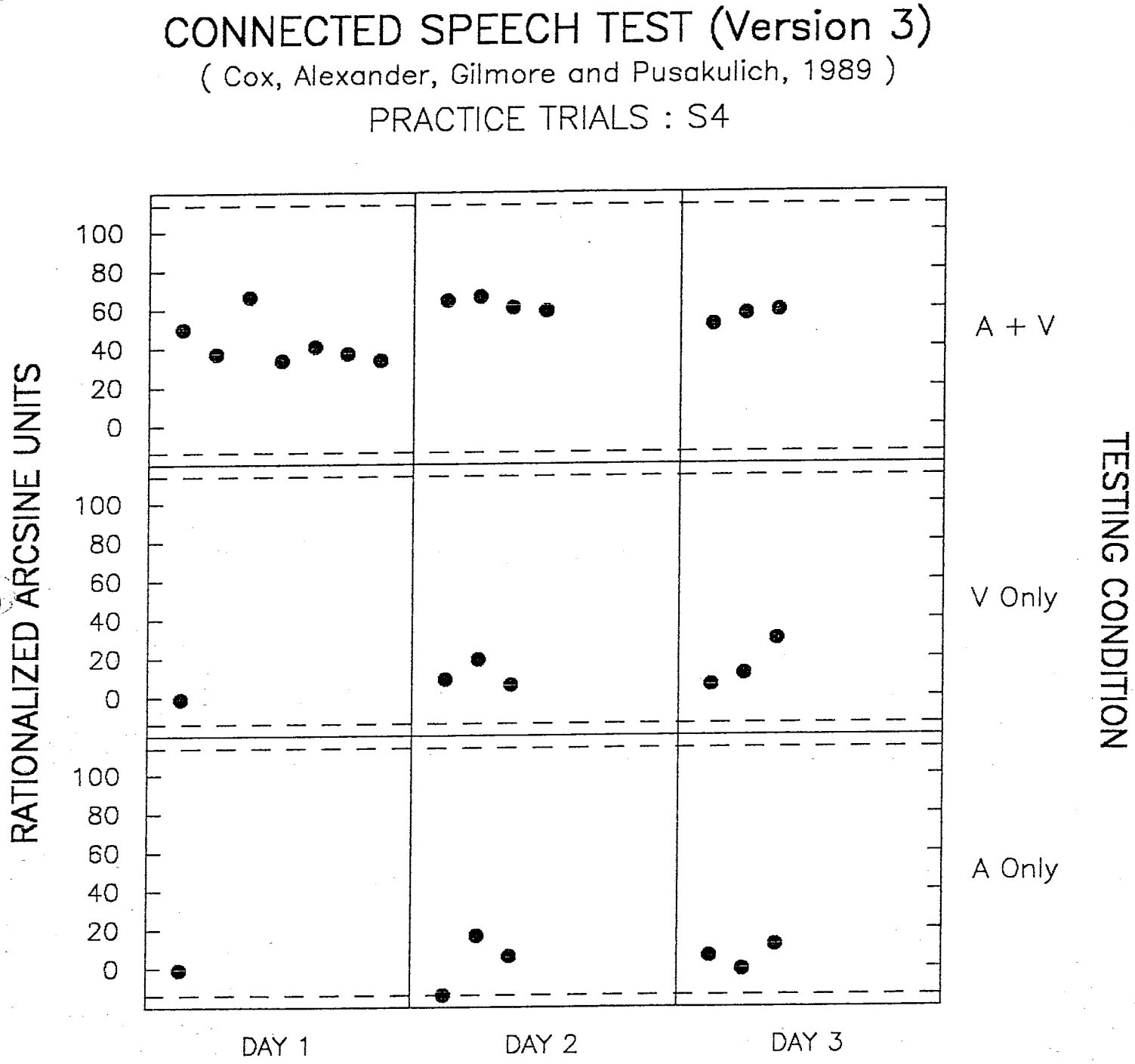

Figure 4. Individual passage scores (rau) on practice trials on the Connected Speech Test Version 3 for the three conditions (audition-plus-vision: A+V; vision only: V; audition only: A) for subject 4.

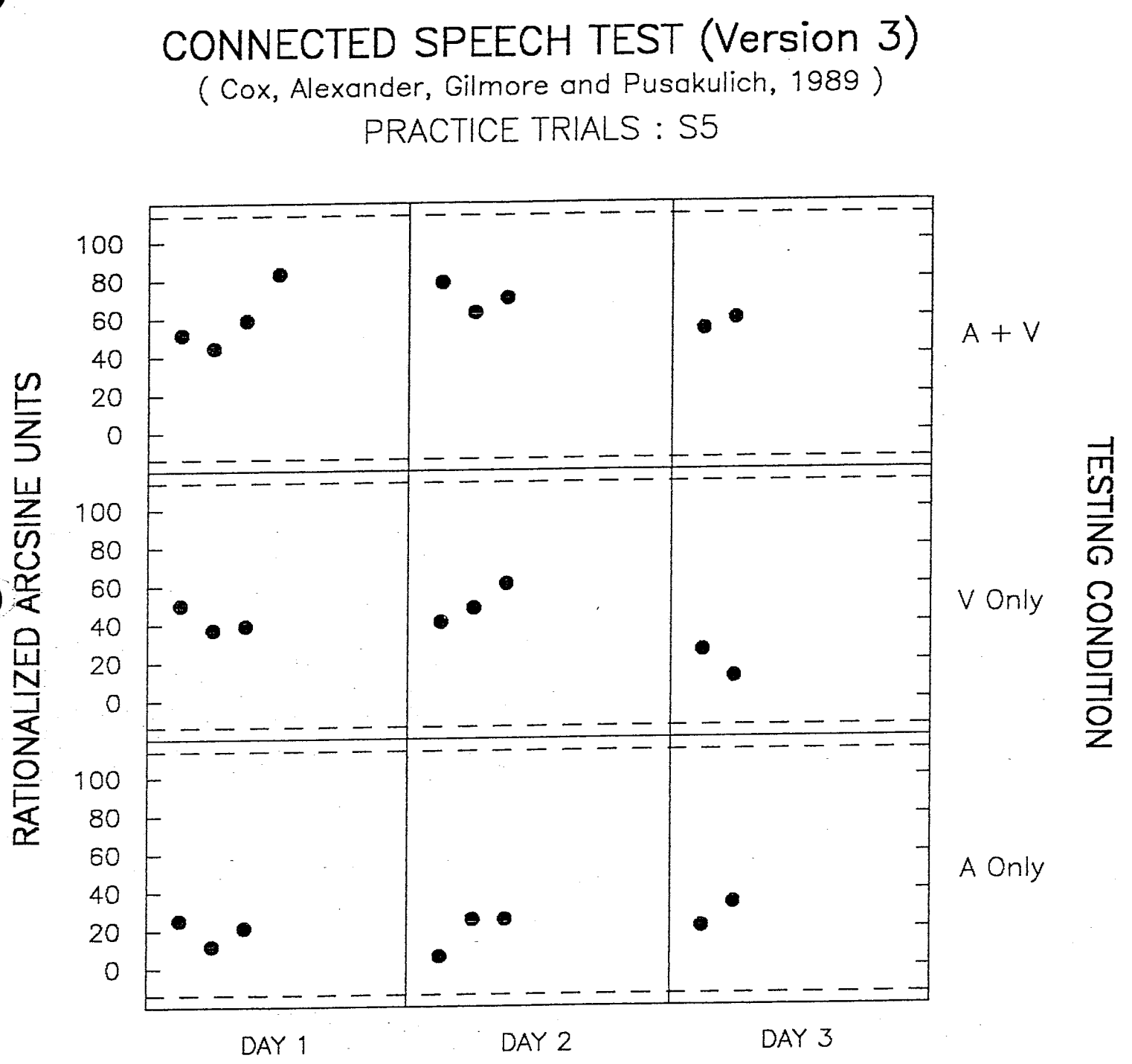

Figure 5. Individual passage scores (rau) on practice trials on the Connected Speech Test Version 3 for the three conditions (audition-plus-vision: A+V; vision only: V; audition only: A) for subject 5.

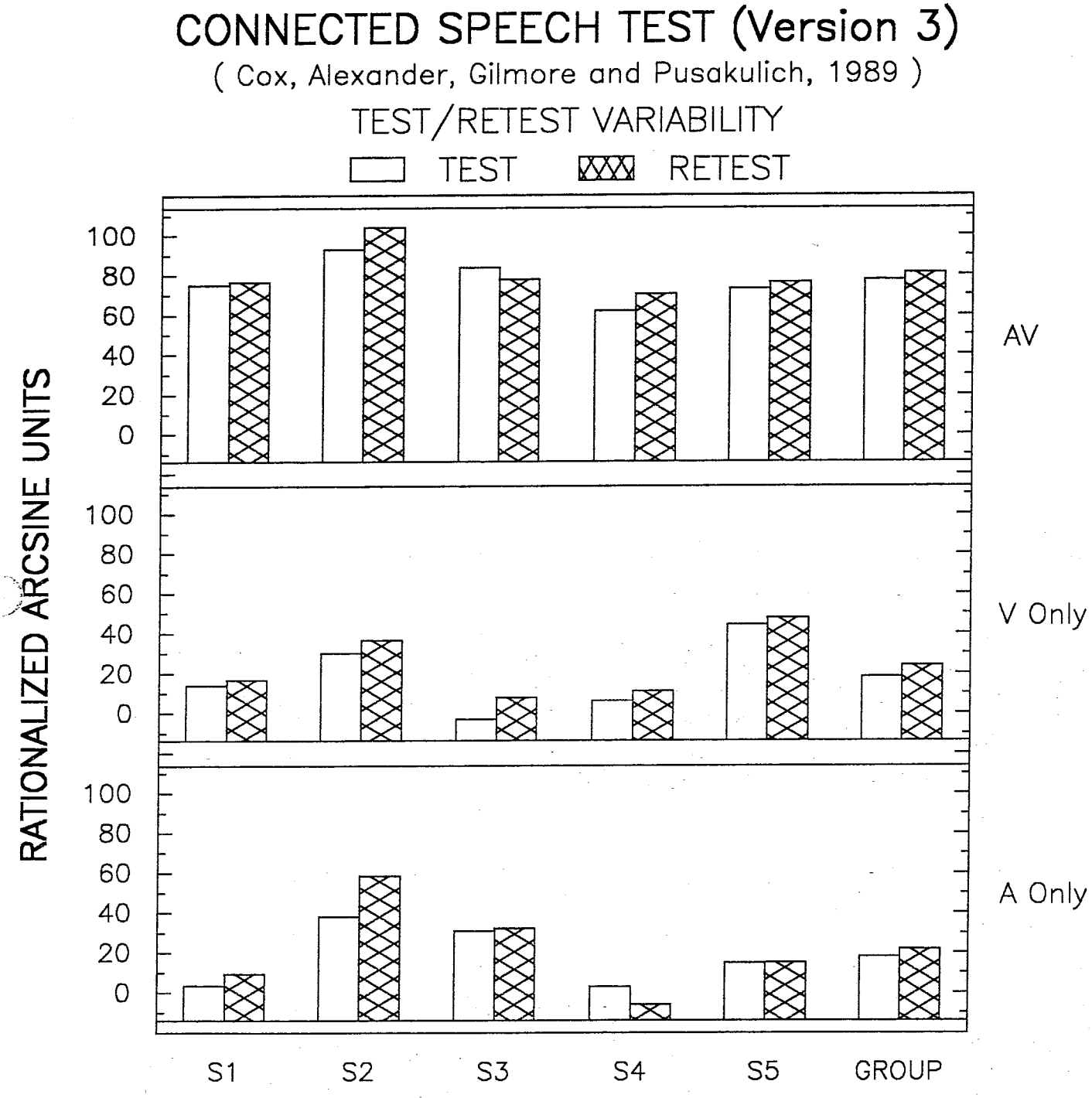

Figure 6. Mean scores (rau) for each subject and the group for a set of six passages (A+V: passages 7-12; V: passages 13-18; A: passages 19-24) of the Connected Speech Test Version 3 presented twice (test and retest) for each of the three conditions (A+V, V, A).

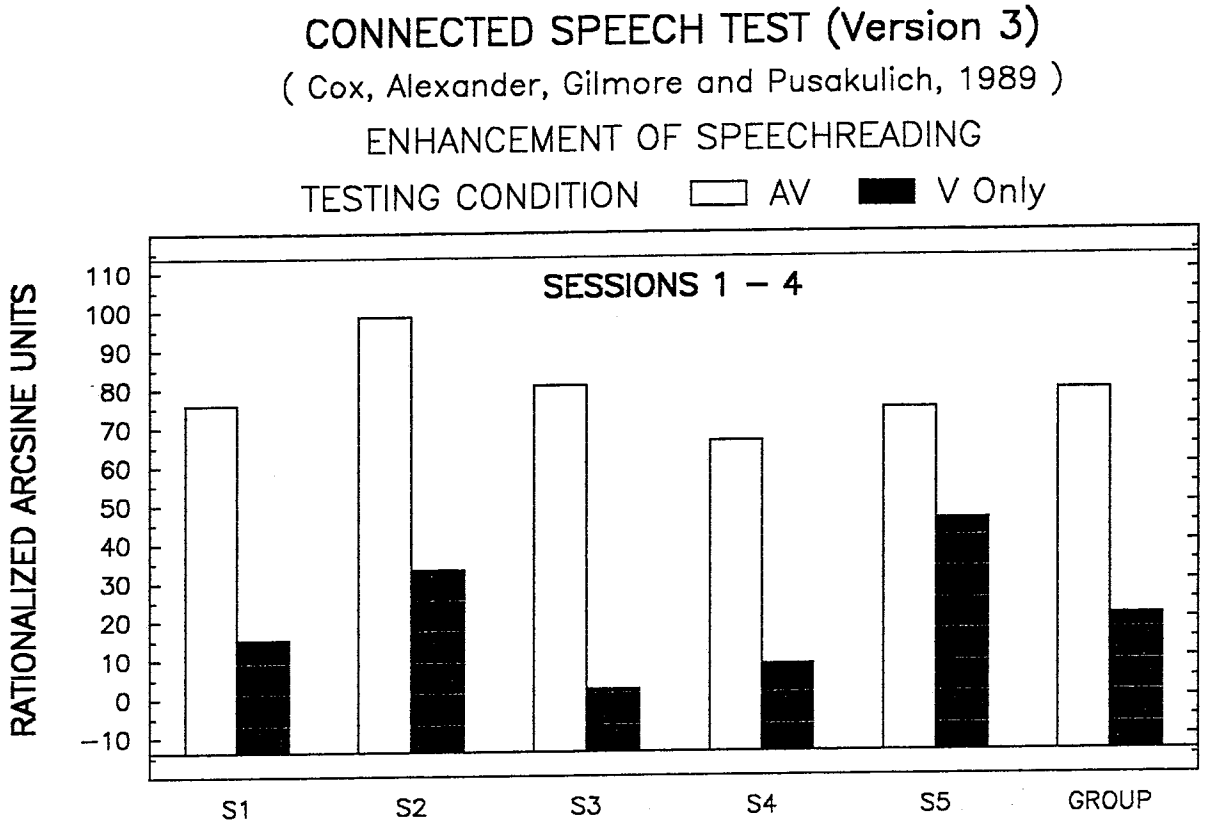

Figure 7. Mean scores (rau) for each subject and the group (across two sets presented during sessions 1 through 4) for the audition-plus-vision (AV) and the vision-only (V) conditions. The difference between the scores in the AV and V conditions is the amount of enhancement provided by the cochlear implant.

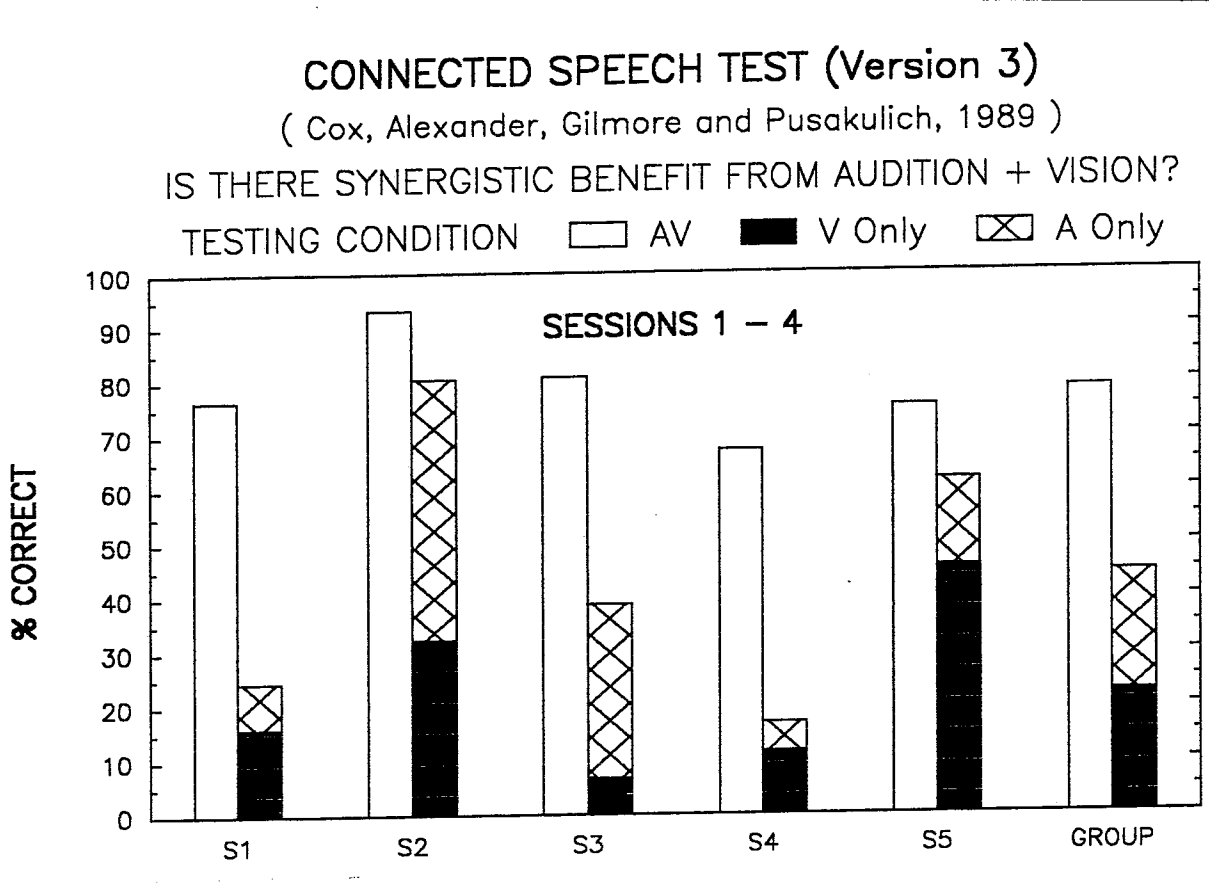

Figure 8. Mean scores (percent correct) for each subject and the group (across two sets presented during sessions 1 through 4) for the audition-plus-vision (AV) condition, the vision-only (V) condition, and the audition-only condition on the Connected Speech Test Version 3. The amount of synergistic benefit is the difference in score between the AV condition and the V plus A conditions for each subject and the group.

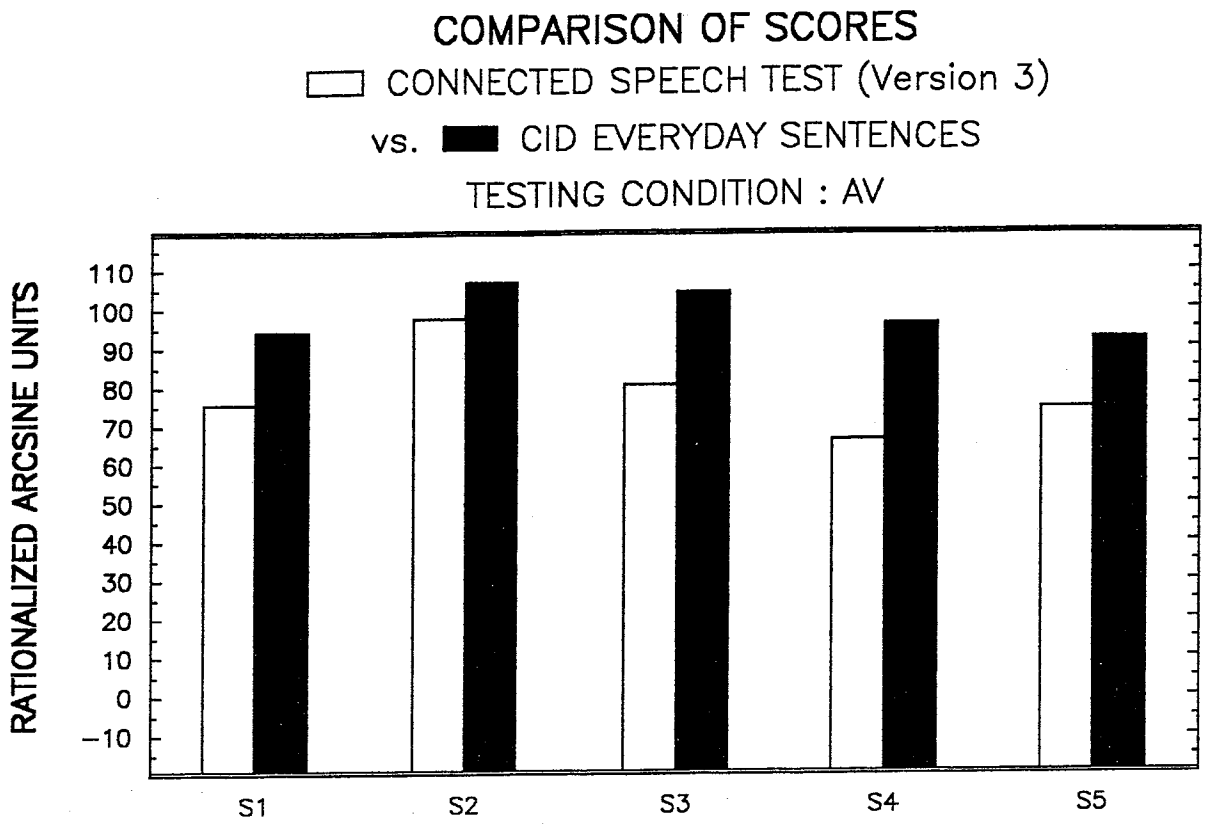

Figure 9. Comparison of mean scores (rau) across 300 key words for the Connected Speech Test Version 3 and the CID Everyday Sentences Test (Johns Hopkins recording) presented in the audition-plus-vision condition for the five subjects and the group.