Veterans Administration

Journal of Rehabilitation Research and Development, Vol. 23, No. 1, 1986
pages 129–138

Continuing Evaluation of the Queen's University Tactile Vocoder II: Identification of Open Set Sentences and Tracking Narrative

P. L. BROOKS, Ph.D.
B. J. FROST, Ph.D.
J. L. MASON, Ph.D.
D. M. GIBSON, M.Sc.

Departments of Psychology and Electrical Engineering
Queen's University
Kingston, Ontario, Canada K7L 3N6

Abstract—Identification of open set words by an experienced normal hearing subject using the tactile vocoder developed at Queen's University was examined. The tactile vocoder filters and processes the acoustic waveform into 16 filter channels each of which activates a vibrator on the skin surface.

After acquiring a 250-word vocabulary through the tactile vocoder, the subject was presented with 1000 different open set sentences in two reception conditions. The percentages of words correctly identified within the sentences in the lipreading (L) and lipreading plus tactile vocoder (L + TV) conditions were 57.8 percent and 79.6 percent, respectively. After two presentations of the stimulus sentences, the number of sentences repeated verbatim in the L + TV condition was 58.4 percent, which was 27.8 percent higher than scores obtained in the L condition.

Performance on the tactile vocoder was also evaluated using the "tracking procedure," in which phrases of text are read to the subject who attempts to repeat the material verbatim. The final tracking rate obtained using lipreading was 15.3 words per minute, which was considerably lower than the L + TV tracking rate of 49.3 words per minute. The tactile vocoder provided valuable information which improved the subject's lipreading ability.

EXPERIMENT 1: IDENTIFICATION OF OPEN SET SENTENCES

Introduction

The experiments described in this paper are part of an ongoing evaluation of a tactile vocoder that has been developed at Queen's University.

The previous paper described experiments in which an experienced artifically-deafened subject was presented with open set words which she attempted to identify using information obtained solely through the tactile vocoder (1). Of the 1000 words presented, 88 of them were identified correctly, and further analysis revealed that 36.7 percent of phonemes in response words were correct.

In the everyday environment, the tactile vocoder will probably be used in conjunction with lipreading, so analyses were also undertaken to examine this. Lipreading identification of open set words was improved when information from the tactile vocoder was added. When lipreading and the tactile vocoder were used in

conjunction, 85.5 percent of the phonemes in words were correctly identified, which was 26.6 percent higher than performance using lipreading alone.

Language skill is an important factor in speech perception, and in the Queen's University word-identification experiments the subject was able to use knowledge of phonemic frequencies, sequencing rules, and word structure to decrease the number of response alternatives. If sentences were used as stimuli, contextual cues could be further increased because syntactic and semantic information would also be available. Shannon (2) has stated that in printed English text the average new information contributed by a letter is approximately one bit, whereas each letter would contain 4.76 bits if all letters were equally likely to occur.

Although contextual information is increased by using sentences instead of words, an individual is faced with the problem of segmenting the continuous speech stream into words. Silent intervals do not exist between words, as the examination of sound spectrograms has revealed. The ability of humans to parse continuous speech into words has puzzled researchers, and this ability is not yet fully understood.

The vast majority of research evaluating vibrotactile aids has used single phonemes, CV's and words as test stimuli. There are only a few studies in the literautre that describe the use of sentences to test performance on a tactile vocoder aided by lipreading. The earliest study of this kind was reported by Gault in 1928 (3). Results are difficult to summarize, because different subjects with various amounts of training were tested under different conditions. However, in one experiment, seven deaf subjects with previous training ranging from 0 to 43 hours were tested on 28 sentences using lipreading (L) and lipreading plus the Teletactor (L + TT). The average number of correct sentence identifications was 12.7 percent for lipreading and 20.3 percent for lipreading plus the Teletactor. When correct words were counted within the sentences, the differences between the L and the L + TT conditions diminished; using lipreading alone, 49.8 percent of words were correctly identified, which is similar to the 53.3 percent correct scored in the Teletactor-aided condition.

A study that resembles more closely the Queen's University experiment was reported by Scott, DeFilippo, Sachs, and Miller in 1977 (4). In their study, two normal-hearing subjects were presented with sets of 44 sentences under three conditions: lipreading (L), lipreading plus a vibrator (L + V), and lipreading plus the vibrator and an electrotactile channel (L + V + E). After one reading, the number of words correctly identified in the sentences was 57 percent for the two tactile-aided conditions. This was 7 percent higher than the score for lipreading alone.

The same data were also analyzed by counting the number of sentences that were reported verbatim. After the first presentation, scores on all three conditions were almost equal for Subject 1 (average of 16 percent correct). Subject 2's scores increased from 32 percent to 48 percent when the vibrator channel was added to lipreading, and to 61 percent when the electrocutaneous channel was used. Following five presentations, the L + V and L + V + E scores showed 16 percent and 21 percent increments, respectively, over the L condition for the two subjects. Thus the tactile information was an effective supplement to lipreading of connected discourse.

In the following experiment, similar in design to that reported by Scott, et al. in 1977 (4), sentences were used as stimuli to allow the effects of increased context, and the word boundary problem, to be examined when the tactile vocoder was used in conjunction with lipreading. In addition, using sentences allowed evaluation of the tactile vocoder in a situation that approximates the everyday environment more closely than does identification of isolated words.

Method

Subject—The normal hearing subject described in the previous Queen's University paper also participated in this study. She had received a total of 196 hours of practice on the tactile vocoder systems prior to the start of this experiment.

Apparatus—The fourth-generation tactile vocoder, described in detail in the previous Queen's University paper, was used again in this experiment.

Procedure—The subject and the reader sat in adjoining sound-attenuating booths, separated by four panes of glass. The subject wore earplugs, and headphones carrying white noise to mask noise from the vibrating solenoids.

The stimuli used in the experiment were 2000 open set English sentences which had an average length of 5.9 words. "Open set" refers to the fact that the subject was not previously shown a list of possible alternatives on which to base the response. Sentences were found in a sign language manual (5) and in a text of English exercises for foreign students (6). Sentences from the latter source can be found in the appendices in Brooks (7). The reader

selected 2000 sentences whose length ranged from 4 to 15 syllables, and copied these into 80 tests of 25 sentences. These sentences were not shown to the subject prior to testing. Although no attempt was made to ensure uniform sentence difficulty, in each single session the material for the lipreading and the lipreading-plus-tactile-vocoder conditions was drawn from the same source and the same exercise. Thus, material tested within a single session was approximately of equal difficulty.

A one-half-hour session per day was spent on sentence identification, with half of that time under the lipreading-alone condition (L) and the other half of the session with lipreading plus the tactile vocoder (L + TV).

The first sentence was read to the subject in a clear, normally paced voice, and the subject attempted to repeat the sentence. If the subject's response was identical to the stimulus sentence, the subject was informed, and the next trial began. If the response was not perfectly correct, the reader repeated the sentence, giving neither visual nor verbal indication of where the errors had occurred. No more than two presentations were allowed, with feedback following the subject's second response.

This procedure continued until the 25 sentences of the test had been delivered by the reader. The subject then adjusted the ON/OFF switch to set the second experimental condition, and another 25-sentence test was given. The experiment was concluded when 1000 different sentences had been presented in each condition. The total amount of time these sessions took was 20 hours.

Preliminary training using sentence material was not given prior to the start of this experiment, and the subject had not had previous experience integrating lipreading and the tactile information.

(It should be noted that the subject was undergoing other experiments using the tactile vocoder during this time. Each day a half-hour session was also devoted to tracking experiments (L, L + TV), to word identification experiments (L, L + TV), and to word identification experiments (TV). A rest period of at least half an hour occurred between sessions, and the order of the four daily sessions was randomly determined.)

Results

A sentence was scored correct by the reader if the response sentence was identical in all respects to the stimulus sentence. After one presentation, 19.2 percent of the 1000 sentences were correctly identified in the L condition, whereas 36.4 percent of the sentences were correct in the L + TV condition. Thus scores were 17.2 percent higher when the tactile vocoder was employed, which represents an improvement of 89.6 percent. After two presentations, 30.6 percent of the 1000 sentences were correct in the L condition and 58.4 percent in the L + TV condition. With the tactile vocoder the subject's scores increased 27.8 percent, which is a 91.0 percent improvement in performance. Figures 1 and 2 display the percentage of sentences that were correctly identified after one and two presentations. The data were calculated over blocks of 100 sentences in the order presented.

The data were also analyzed by determining the number of **words** correctly identified after two presentations. An average of 5923 words were presented in each condition. In the L condition 57.8 percent of the words were correctly identified, whereas in the L + TV condition 79.6 percent were identified correctly. Thus, when information from the tactile vocoder was added to lipreading, 21.8 percent more words were identified correctly. Figure 3 displays the percentage of words correctly identified in the two conditions after two presentations of the sentences. Percentages were averaged over blocks of 100 sentences.

Stimuli (S) and responses (R) from a representative lipreading and a lipreading-plus-tactile-vocoder session are shown in Tables 1 and 2. This session occurred within the last block of sentences shown in the figures. Indication of whether the response was correct after the first (1) or second (2) trial is given, and if the response was incorrect after two trials, the incorrect response is shown.

Discussion

The results of this experiment clearly demonstrate the tactile vocoder's ability to provide information to improve lipreading. After a single reading of the sentences, L + TV scores for repeating material verbatim were 17.2 percent higher than scores for L alone and following two presentations, L + TV scores were 27.8 percent higher. In both cases, performance scores almost doubled when information was furnished through the tactile vocoder. The total number of words correctly identified in these sentences was 79.6 percent when information from

TABLE 1
Sentences: Lipreading.
Sample Stimulus (S) and Response (R)

S It was kind of you to think of me.
R (2)

S He is separated from his wife.
R (1)

S The grass is green now.
R (1)

S She was very good company.
R She was very interesting.

S Do you recognize that man?
R (1)

S He prepared a dangerous experiment.
R _____ in America.

S He slipped and fell as he crossed the road.
R He somehow fell when he crossed the road.

S I lost my pen and pencil.
R (1)

S I have an important meeting tonight.
R (1)

S I forgot to wind the clock last night.
R (1)

S Her perfume smelled wonderful.
R Her _____ wonderful.

S The poor boy was hit by lightning.
R (1)

S There was a house fire last night.
R (1)

S The pencil sharpener is broken.
R The patient sharped for his.

S He recognized me at once.
R He waited and _____

S Did you sleep well last night?
R Did you ____ well last night?

S I am delighted to meet you.
R I am _____ to miss you.

S The kettle is boiling.
R The ____ this morning.

S He will be asleep for hours.
R He will bring some flowers.

S What did you eat? Your tongue is purple.
R What is _____ is purple.

S My ankle is swollen.
R *My head hurts this morning.*

TABLE 2
Sentences: Lipreading Plus Tactile Vocoder
Sample Stimulus (S) and Response (R)

S Empty that dirty water.
R _____ water.

S Would you like a cup of tea?
R (1)

S There are two bridges that cross the river.
R (1)

S He will return in an hour.
R (2)

S I accept your invitation.
R (1)

S I'm afraid I have some bad news.
R (2)

S It's difficult to understand him.
R (1)

S I like swimming in the sea.
R (1)

S He hit me on the head with a stick.
R He came along the highway sick.

S She lives down the street from me.
R (1)

S We must always follow the law.
R (1)

S That big lunch made me full.
R (2)

S I forgot the key to my house.
R (2)

S Don't give up so easily.
R (1)

S He cut himself while shaving.
R (1)

S I need a new pair of shoes.
R (1)

S Hide in the box before he comes.
R (2)

S Both of us were very tired.
R (1)

S She could not start her car.
R She _____

S He wore a grey business suit.
R He wore a grey _____ suit.

NUMBERS in parentheses indicate whether response was correct after first (1) or second (2) trial. If response was incorrect after two trials, incorrect response is shown.

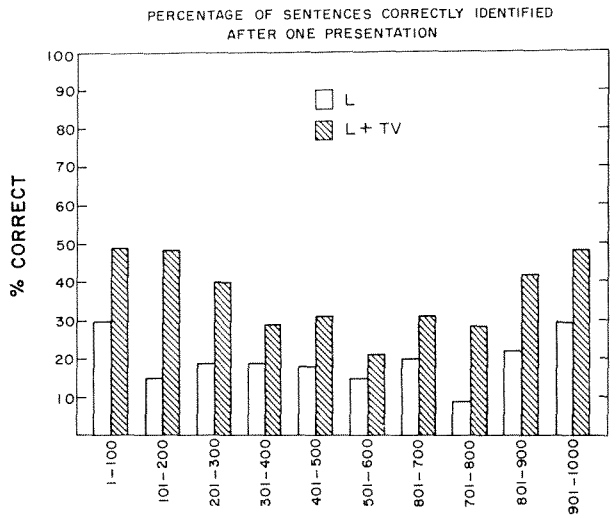

FIGURE 1
Percentage of sentences identified correctly by a normal-hearing subject after one presentation using lipreading (L) and lipreading plus tactile vocoder (L + TV). The 1000 different sentences presented in each condition are displayed in blocks of 100 sentences.

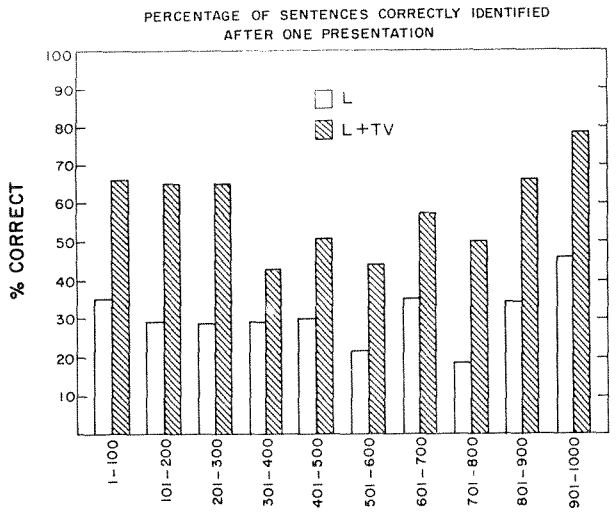

FIGURE 2
Percentage of sentences identified correctly by a normal-hearing subject after two presentations using lipreading (L) and lipreading plus tactile vocoder (L + TV). The 1000 different sentences presented in each condition are displayed in blocks of 100 sentences.

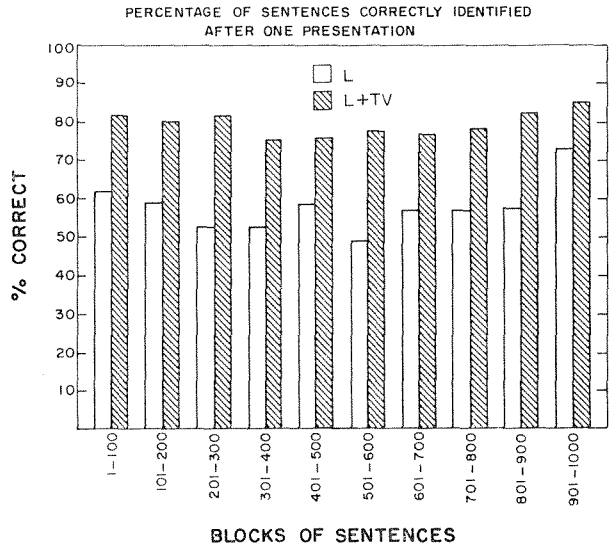

FIGURE 3
Percentage of words identified correctly by a normal-hearing subject after two presentations using lipreading (L) and lipreading plus tactile vocoder (L + TV). Percentages were calculated over blocks of 100 sentences.

both the tactile vocoder and lipreading was available; this was a 21.8 percent improvement over lipreading-alone scores.

It was apparent that the integration of the two modes of information was not difficult even for a subject who had not received training combining lipreading and the tactile vocoder prior to this experiment. On the first 100 sentences presented, 48 percent were repeated verbatim in the L+TV condition, whereas a score of only 30 percent was obtained with lipreading alone. In these 100 sentences 82 percent of the words were correctly identified when the tactile vocoder supplemented lipreading. This indicates that speech features can be extracted independently from different modalities and combined by a higher-level processor. A similar extraction and integration seems to occur when severely hearing impaired individuals supplement residual hearing with lipreading information.

The subjects, stimuli, and methodologies in this experiment, and in the one reported by Scott et al. in 1977 (4), are similar enough to allow the results to be compared. The two subjects in Scott et al. (referred to as SA and SB), and the one in the present study (S1), all had normal hearing and had received experience on tactile systems. In the present study the data were based on 1000 sentences per condition, whereas in the Scott et al. study percentages were calculated on 44 sentences. There were, however, important differences in the tactile systems. Scott et al. used a 3-channel hybrid system that displayed the amplitude envelope of the speech signal, whereas the tactile vocoder used in this experiment contained 16 channels.

For the lipreading condition, the percentages of sentences correctly identified after a single reading were 19.2, 18 and 32 percent for S1, SA and SB respectively, indicating that SB was a superior lipreader. With the addition of the tactile information, performance improved by 17.2 percent for S1, a negligible amount for SA and 29 percent for SB. After two presentations of the sentences, the lipreading scores were 30.6, 37 and 65 percent for S1, SA and SB. The addition of the tactual aid improved S1's performance by 27.8 percent, SA improved by 7 percent and SB showed an increase of 24 percent. It would be difficult to choose one device over the other based on the comparison of performance shown here. Tactual aids in both studies improved the subjects' ability to correctly identify sentences, and it is unfortunate that this tactual information, beneficial even though delivered by devices still not perfected, is not available for the profoundly deaf population.

EXPERIMENT 2: EVALUATION OF THE TACTILE VOCODER USING THE TRACKING PROCEDURE

Introduction

A method called the "tracking procedure" has been developed by DeFilippo and Scott (8) as a means of training and evaluating the reception of ongoing speech. During tracking, a speaker reads a meaningful portion of text aloud, and a receiver attempts to repeat the phrase verbatim. If the subject correctly repeats the phrase, the speaker proceeds with the following phrase. Strategies have been outlined (8) for cases where the response is not verbatim. A words-per-minute (wpm) rate can be obtained for the given reception condition, and this rate can be compared to a normal-listening condition.

The Committee on Hearing, Bioacoustics and Biomechanics (CHABA)* discussed training and evaluation procedures in Sherrick's 1984 report, Research on Tactile Aids for Deaf People: Progress and Prospects (9). The need for standardization in training and evaluation procedures was underscored in the report, and tracking was suggested as one method for training with and evaluating tactile aids.

The tracking procedure has been used as a means of evaluating several tactile aids. DeFilippo and Scott (8) tested two hearing subjects in an unaided lipreading condition (L), in a condition where lipreading was aided by a two-channel aid (L+T), and in a normal-listening condition. The subjects in the experiment were the authors of the paper; they were familiar with the tracking procedure, but they had not used the tactile aid extensively for tracking. Scores were reported as percentages of the tracking rate obtained under normal-listening conditions (113 wpm).

After approximately 21 hours of testing, the final tracking rate for Subject 1 was 37 percent of the normal-listening rate in the L condition and 46 percent in the L+T condition, an improvement of 9 percent. Subject 2, who was a superior lipreader, achieved 45 percent of the normal-listening rate in the L condition and increased to 65 percent when the tactile aid was used. Although the main purpose of that DeFilippo and Scott study was to test the tracking procedure, the results also indicated that the tactile aid had potential as a communication aid. The authors concluded that tracking would be

*CHABA is a committee of the National Research Council established by the National Academy of Sciences. CHABA sets up special "working groups" to advise federal agencies on issues of significant national need.

beneficial for communication training and evaluation of communication systems.

The MESA, or multipoint electrotactile speech aid, described in 1979 by Sparks, Ardell, Bourgeois, Weidmer and Kuhl (10), is another communication system that has been evaluated using the tracking procedure. Two of the three subjects used in the study had had no previous experience with the MESA, whereas the third participant had many hours of experience in identifying segmental speech features. After 15 hours of tracking, the words-per-minute rate found in the lipreading condition was very similar to that obtained with the MESA and lipreading combined. The tracking rate was approximately 40 wpm for the experienced subject, and 65 wpm and 50 wpm for the two inexperienced subjects, regardless of the condition. The authors concluded that the MESA may overload the tactile system when connected speech is used, although such a negative conclusion may be premature, considering the minimal amount of training which was provided.

Grant in 1980 (11) examined tracking performance using an aid in which changes in fundamental frequency were encoded as changes in location of vibration. A normal-hearing subject and a profoundly deaf subject reached final tracking rates of 60.6 and 77.0 percent, respectively, of the normal auditory tracking rate after training 10 hours using lipeading alone and 10 hours using lipreading plus the tactile aid.

In the Queen's University experiment the tactile vocoder was evaluated using the tracking procedure. The stimuli used in tracking contain more contextual information than unrelated sentences do, since information about the author's vocabulary, style, characters, and plot are present. This allows examination of performance on the tactile vocoder in a situation that resembles normal communication more closely than does identification of unrelated sentences. It also allows comparison among various tactile aids and cochlear prostheses.

Method

Subject and Apparatus—The subject and apparatus were identical to that described in Experiment 1.

Procedure—The two readers (Reader 1 and Reader 2) were female undergraduate students who were not familiar with the tracking procedure, linguistics, or the inherent problems in lipreading. Prior to the beginning of the experiment, the readers were provided with a 1-hour instruction period on the tracking procedure.

The material chosen for tracking was "Miranda in the Middle" (12) a novel written for adolescents. This text contains dialogue typical of conversations that occur in the everyday environment (Table 3).

During tracking, the reader established eye contact with the subject and then read a meaningful phrase of text at a normal speaking rate. The subject attempted to repeat the phrase verbatim. If the repetition was not perfectly correct the reader adopted one of the strategies outlined in detail by DeFilippo and Scott (8). If the subject repeated the phrase verbatim, the reader read the following phrase of the text.

After 5 minutes of tracking a brief break was provided, and then another test session commenced. Words of text correctly identified in the 5-minute session were counted, and then divided by the number of minutes that tracking actually occurred. (This words-per-minute rate should not be confused with words **spoken** per minute, which would be more than twice the tracking rate because "words spoken" includes repetitions and correction strategies.)

The subject was tested using the tracking procedure under lipreading (L) and lipreading-plus-tactile-vocoder (L + TV) conditions. Five 5-minute L + TV sessions, and for comparison two 5-minute L sessions, were given on a daily basis. In total, approximately 5.5 hours of testing occurred under L + TV and 2.0 hours under L. Reader 1 was present for the first 15 sessions (Days 1 through 3) of testing and Reader 2 remained for the last 50 sessions (Days 4 through 13).

A control tracking rate was obtained for a normal-listening condition using Reader 2. Subject and reader faced each other in a room illuminated by overhead fluorescent lights. In this case the subject used both hearing and lipreading to determine what had been said. The same testing procedure as that already described was followed, including establishment of eye contact between the subject and reader before a phrase was read. This experiment was run concurrently with Experiment 1 and open set word identification experiments.

Results

The words-per-minute (wpm) tracking rates were averaged over the five daily L + TV sessions and the two daily L sessions. Rates for the L and L + TV conditions are plotted in Figure 4. Reader 2 was introduced after the initial 15 sessions, as is indicated by the arrow in the baseline of Figure 4. By the end of the 65 sessions the subject was tracking at 49.3 wpm when both the tactile vocoder and lip-

reading were employed, which was faster by 34.0 wpm, or 3.2 times faster, than the final rate of 15.3 wpm obtained with lipreading alone. In every instance, the L + TV rates were higher than the L rates, with the average advantage in the L + TV condition being 20.4 wpm (s = 11.3).

Over the course of this experiment there was a general increase in the words-per-minute rate in the L + TV condition. The subject started tracking at 18.6 wpm, and increased over 3 days to 32.0 wpm with Reader 1. The rate dropped back (19.3 wpm) to approximately the initial rate when Reader 2 was introduced, but increased over the following 10 days to the rates obtained with the previous reader. Over the 50 sessions of tracking with Reader 2 the subject's rate increased to 49.3 wpm, which was 30.0 wpm faster than the initial rate obtained with this reader.

In contrast, the lipreading rate did not vary noticeably over time. The average lipreading rate was 13.8 wpm, and the standard deviation of 3.5 indicates the scores did not vary greatly from the mean.

To facilitate comparison among studies using tracking as an evaluation procedure, the words-per-minute rates are presented also as a percentage of the normal-listening rate (indicated on the right-hand vertical scale of Figure 4). It was hoped that this would partly control for text difficulty, thereby increasing the validity of comparisons among results from different studies. The final lipreading rate was 18.9 percent of that obtained under normal-listening conditions, whereas the wpm rate in the L + TV condition was 60.8 percent of the auditory rate, an increase of 41.9 percent. The average percentage advantage of the L + TV condition over L was 25.2 percent (s = 13.9).

An example of exchanges that occurred between Reader 2 and the subject in the lipreading-plus-tactile-vocoder condition is shown in Table 3. The tracking rate in the session where this excerpt was taken was 48 wpm.

Discussion

The final tracking rate attained by the subject strongly indicates that the tactile aid could provide invaluable information for the postlingually deafened individual. The addition of the tactile vocoder improved performance by 34.0 wpm, to a rate 60.8 percent of what would be expected by a hearing individual. This level of performance was achieved after approximately 200 hours of training on various materials and tactile vocoder systems, but after only 5.5 hours of training using the tracking procedure with the tactile vocoder.

The lipreading tracking rate did not vary noticeably over time. This is not surprising, since only a 2-hour period of testing occurred. Most normal-

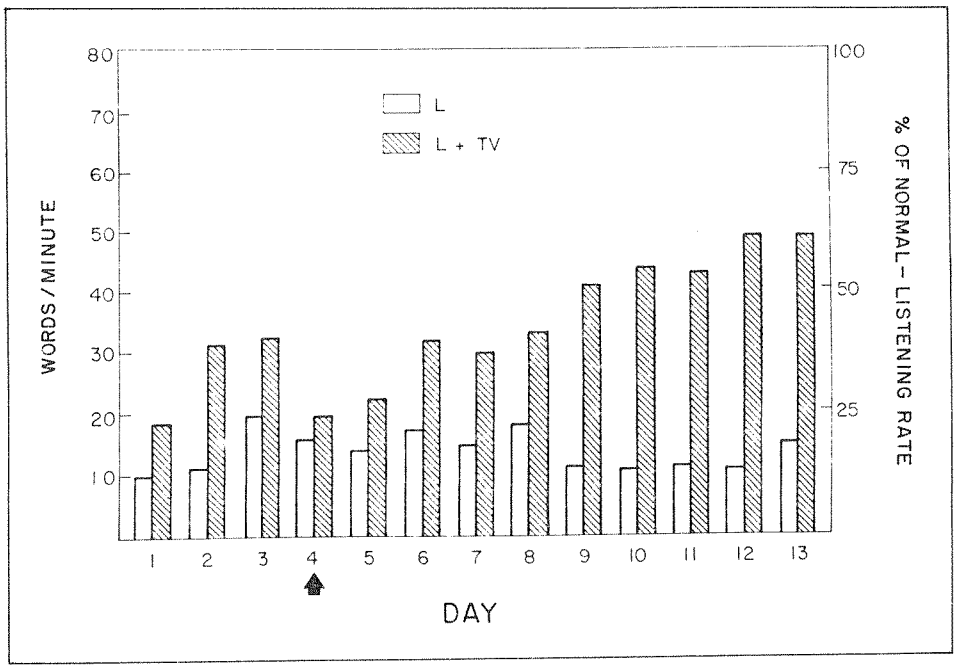

FIGURE 4
Words-per-minute (wpm) tracking rates for a normal-hearing subject. Left axis indicates absolute wpm rate and right axis indicates wpm rate as percentage of normal-listening rate. Readers were changed on the 4th day, as is indicated by the arrow.

hearing individuals acquire some degree of lipreading facility in connection with everyday speech comprehension, and it is unlikely that the 2 additional hours of lipreading practice provided in this experiment changed the subject's lipreading ability.

Calculation of words-per-minute rates as a percentage of the normal-listening rate makes it possible to compare studies. The magnitude of improvement of the lipreading-plus-tactile-vocoder over lipreading alone in the present study was greater than any improvement previously reported. DeFilippo and Scott's (8) Subjects 1 and 2 increased 9 percent and 20 percent, whereas in the present study the improvement was 41.9 percent.

Major differences that exist between the two studies could explain such discrepancies in accomplishment. The subject in this study had reached the point in training where many novel words and phonemes could be identified through the tactile vocoder alone, whereas DeFilippo and Scott's subjects had accumulated very few hours of training with the tactile aid unaided by lipreading. Thus, the relative amounts of information that the tactile devices were supplying could differ due to the difference in the amount of training received. Secondly, the type of information supplied by the tactile devices differed enormously; the frequency resolution that would be possible with Scott and DeFilippo's aid was minimal compared to that of the Queen's University tactile vocoder.

The normal-listening tracking rate obtained in this study was 81 wpm, a slower rate than the 113 wpm obtained by DeFilippo and Scott (8) and the 111 wpm rate reported by Sparks et al. (10). However, this study's normal-listening tracking rate was approximately half of the normal oral reading rate of 160 to 180 wpm (13), which should be expected since in tracking everything is repeated twice. The discrepancy between the normal-listening rate in this study and in other studies may be due to small methodological differences in obtaining the rate.

The experiments reported here were undertaken with a single normal-hearing subject, which makes generalization of the results difficult. It was necessary in the early stages of system development to use a normal-hearing subject because ethical problems arise if a device of unknown benefit is tested on a profoundly deaf child. Secondly, in view of the time constraints involved in evaluation, a better estimate of the potential of the device is likely to be obtained by testing a single, experienced subject on increasingly complex tasks than by testing numerous naive subjects on simple discrimination tasks.

TABLE 3
Excerpt of Stimuli (S) and Responses (R) from a Tracking Session: Lipreading Plus Tactile Vocoder

S This is the first time I've seen the river from this high up.
R first time I've

S This is the first time I've seen the river
R This is the first time I've seen the river

S from this high up.
R from this high up.

S Miranda was just showing me the north view.
R Miranda was just showing me the gorgeous view.

S the north view
R the north view

S You guys are really lucky to live here.
R I was really lucky to live here.

S You guys are really lucky to live here.
R You guys are really lucky to live here.

S I know, said Alex.
R I know, said Alex.

S It's great.
R It's great.

S Uh, where do you live?
R Why, where do you live?

S Uh, where do you live
R Uh, where do you live?

S as if he didn't know.
R I live in

S as if he didn't know.
R I've

S as if he didn't know.
R as if he didn't know.

S I live right next door.
R I live right next door.

S You can probably even see my window from here. You can probably
R You can probably

S even see my window from here.
R You can probably even see my window from here.

It would be interesting to compare the tracking rates obtained in this study with those obtained by cochlear implant patients. One of the most successful multichannel cochlear implants is the

Nucleus, developed by Clark et al. and reported in 1983 (14). Briefly, the 22 electrodes in that system receive input from a speech processor that preserves voicing frequency and provides some place-pitch information. The length of time subjects wore the aid before testing began is not stated. However, since the cochlear prosthesis is wearable it can probably be assumed that a substantial amount of experience using the cochlear prosthesis had been obtained. Four patients implanted with the Nucleus system reached final lipreading-alone tracking rates between 17 and 26 wpm, whereas the rates with implant-plus-lipreading ranged from 31 to 52 wpm. Average improvement was 21.2 wpm. The subject in the Queen's University tactile vocoder study reached a final tracking rate of 15.2 wpm using lipreading and 49.3 wpm in the aided condition, which represents a 34.1 wpm increase in the tracking rate. The Nucleus and the tactile vocoder thus seem to offer similar benefits to the user for the tracking task.

CONCLUSION

In conclusion, the Queen's University tactile vocoder has been evaluated extensively using environmental sounds (15), CVs (15, 1), closed set words (16), open set words, open set sentences, standardized tests (7), and the tracking procedure, in situations where information was obtained solely through the tactile vocoder or the tactile information was supplemented by lipreading or hearing aids. Performance has been examined using normal-hearing subjects (15, 16), a postlingually profoundly deaf subject (15), and prelingually profoundly deaf subjects (7, 1). A tremendous amount of information is available through the tactile vocoder that could improve the speech comprehension of the profoundly deaf individual. Research effort is now being directed at producing a wearable tactile vocoder■

REFERENCES

1. Brooks PL, Frost BJ, Mason JL, and Gibson DM: Identification of words and manner features of speech by profoundly deaf subjects using the tactile vocoder. J Speech Hear Res (in press).
2. Shannon CE: Prediction and entropy of printed English. Bell System Technical Journal 30:50-64, 1951.
3. Gault RH: Interpretation of spoken language when the feel of speech supplements vision of the speaking face. Volta Rev 30:379-386, 1928.
4. Scott BL, DeFilippo C, Sachs R, and Miller J: Evaluating with spoken text a hybrid vibrotactile-electrotactile aid to lipreading. Papers from the Research Conference on Speech-Processing Aids for the Deaf (pp 106-118), Gallaudet College, Washington, D.C., 1977.
5. O'Rourke TJ: A Basic Course in Manual Communication (pp 107-119 and 150-161). Silver Spring, Maryland; National Association of the Deaf, 1973.
6. Clarke DM and MacKenzie MDM: Modern English Practice: Exercises in English for Foreign Students. London, Longman Group Ltd., 1957.
7. Brooks, PL: Comprehension of Speech of Normal-Hearing and Profoundly Deaf Subjects Using the Queen's University Tactile Vocoder. Unpublished Doctoral Dissertation, Queen's University, Kingston, Canada, 1984.
8. DeFilippo CL and Scott BL: A method for training and evaluating the reception of ongoing speech. J Acoust Soc Am 63(4):1186-1191, 1978.
9. Sherrick CE: Research on tactile aids for deaf people: Progress and Prospects. J Acoust Soc Amer 75(5):1325-1342, 1984.
10. Sparks DW, Ardell LA, Bourgeois MR, Wiedmer B, and Kuhl PK: Investigating the MESA (multipoint electrotactile speech aid): The transmission of connected discourse. J Acoustic Soc Am 65(3):810-815, 1979.
11. Grant KW: Investigating A Tactile Speechreading Aid: The Transmission of Prosodic Information in Connected Discourse and Sentences. Unpublished M.S. Thesis, University of Washington, 1980.
12. Winthrop E: Miranda in the Middle. New York, Bantam Books, 1980.
13. Gilbert JH: A note on oral reading rate. J Speech Hear Res 11:219-223, 1968.
14. Clark G, Dowell R, Brown A, Luscombe S, Pyman B, Webb R, Bailey QE, Seligman P, and Tong Y: The clinical trial of a multiple-channel cochlear prosthesis: An initial study on four patients with profound-total hearing loss. Med J Austral 2(9):430-433, 1983.
15. Scilley PL: Evaluation of a Vibrotactile auditory prosthetic device for the profoundly deaf. Unpublished M.A. Thesis, Queen's University, Kingston, Canada, 1980.
16. Brooks PL and Frost BJ: Evaluation of a tactile vocoder for word recognition. J. Acoust Soc Am 74:34-39, 1983.