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ABSTRACT

Four hearing Ss (20- to 30-years old) and 4 deaf Ss (8- to 14-years old) trained in speech discrimination using a vocoder (a device which converts speech into tactual vibrations received through the skin). Hearing Ss (artificially deafened by white noise transmitted through headphones) received from 20 to 80 hours of training in isolated words presented randomly, words in connected sentences, inflection copying, and rhyming, all of which was presented primarily without face-to-face contact with the speaker. Deaf Ss received training similar to that for hearing Ss with a few differences such as use of a reinforcement system and work on articulation. Results supported conclusions such as the following: that deaf Ss can be taught to hear five speech discriminations through the tactual mode; that hundreds of corrected repetitions are required for either a deaf or hearing S to learn simple tactual discriminations; and that the S's memory and ability to discriminate increases as the number of words he has mastered increases. (LS)

Oregon Research Institute

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TACTUAL HEARING EXPERIMENT WITH DEAF AND HEARING SUBJECTS[1]

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A deaf child is seriously handicapped because he lacks that feedback device possessed by the hearing child--the ear. As a result of feedback deprivation, the deaf child typically has trouble both with cognitive operations and with communication. Often he is seriously retarded in his ability to express ideas or concepts; also, his attempts to speak may merely brand him as a handicapped child. Since he cannot match what he says against the productions of another speaker, he has trouble producing different phonemes; he often inflects words in an unconventional and grating manner; he has poor control of the pitch of his words; and his control of loudness is often tenuous.

The solution to his problem would seem to be simple: provide him with a device that functions like an ear. If the device gave information about pitch, loudness, and about the characteristics of each phoneme, the deaf child would have the feedback information he needs to begin matching his utterances against those of another model.

For over four decades investigators have tried to develop devices that would function as an external ear. These investigators took two different routes: one was the visual route; the other was the tactual route. The visual route was characterized by the use of an oscilloscope, a device that makes a "picture" of the sound energy pattern of an utterance. The game the child

is to play with this device is to look at the patterns that appear on the oscilloscope and "match" them by saying something that produces a picture like the model picture.

The major problem with this approach is that the analogy between the oscilloscopic presentation and the ear is poor from a psychological standpoint. While it may be possible for an oscilloscopic presentation to provide information about phoneme structure, loudness, and pitch, the device involves volition. The subject chooses certain features to attend to, possibly irrelevant details. For a device to be more analogous to an ear it would have to ensure that:

(1) the subject receives the sound, whether or not he wants to receive it.

(2) the various details of the "sound" are expressed as details that are felt by the subject (for example, something loud would feel different from something not loud).

(3) The subject would be able to receive sound information in the range of situations that a hearing subject receives the information; the information would not be restricted to situations in which the subject looked at another person, or looked at a device.

Different investigators, over the past 40 years, have recognized that the tactual vibration strategy would allow for the construction of an external mechanical ear that is consistent with the psychological characteristics of hearing. The device would convert words or sounds into vibration. The vibration would be delivered to the subject. Ideally it would contain information needed for the subject to identify what is said, how it is inflected, how loud it is, and so forth. Hopefully, the nervous system would be adequate to handle this information and allow for accurate perception of what is presented in the form of vibration. The long range goal of the different investigators who experimented with tactual hearing devices, although not

always expressed, was clear. If the device could be perfected and if the subject's nervous system were capable of handling the vibratory information, miniature hardware packages could be designed that would allow the subject to perform in a range of situations from which the deaf child is currently excluded.

The first tactual device was reported by Gault and Crane in 1928. This device amplified sound from a speaker and presented it to a subject as vibration. The device was crude and investigators did not find the results encouraging. During 1949 and 1950, Wiener et al. briefly experimented with a glove (Felix) that was connected to a vocoder. A vocoder is a device used to transmit messages over long-distance telephone cables. It divides the speech spectrum into "channels." For example, one channel might cover the frequency range of 200-240 Hz. Every time energy is present in this range, the channel is activated. The more energy present in the channel the stronger the signal becomes. At the other end of the long-distance line, the energy from all of the channels is reconstructed as speech.

Felix was designed so that different parts of the speech spectrum were displayed on different parts of the hand. The energy from the one part of the spectrum activated vibrators on one finger, while energy from another part of the spectrum activated vibrators on another finger.

Apparently Felix was used only a few times before the investigators abandoned it.

Later attempts to construct a vibratory prosthesis also terminated in discouragement. Guelke and Huyssen (1959), Kringlebotn (1968) and Pickett and Pickett (1963) used sophisticated tactual vocoders but noted that the performance of their subjects was not encouraging.

Kirman (1973), in his review of experiments with tactual vocoders, concluded: "The history of tactile vocoders indicates that simply providing the skin with such frequency-to-locus translators as have been tried does not enable it to comprehend speech." This statement is not an assertion that tactual vocoders cannot work. Kirman also concludes:

> "Neither the results of past work on tactile displays nor contemporary theories of speech perception have provided reasonable grounds for believing that the skin lacks the capacity to comprehend a suitable display of speech."

There are several possible interpretations that would reconcile Kirman's statements:

(1) The vocoding devices used in the past were perfectly adequate to provide the "suitable display", however adequate <u>training</u> was lacking.

(2) The vocoding devices used in the past were not capable of providing the detailed information needed for adequate speech perception.

The hypothesis adopted by the investigators of the present experiment is 1 above. Analysis of the training provided in previous tactual vocoders discloses that the investigators seemed to assume that if the display were suitable (that is, if it provided the information needed for adequate speech perception), the subject would learn quickly, if not instantly. The assumption underlying the present study is that a great deal of practice would be needed (probably at least 1200 corrected trials) before a healthy subject could be expected to perform consistently on each of the early words to be discriminated. This assumption is based on the performance of congenital cataract patients after a surgical removal of the cataracts (Senden, 1932), on the number of trials needed by children who are born deaf but later have their hearing restored through surgery, on the performance of speakers of a foreign language and the number of practice trials needed for them to "perceive" discriminabl

differences in a second language, on the perceptual performance of people such as the Truckees, (who are relatively deprived of practice with certain discriminations), and even by the performance of normal infants who at the age of 12 months often give little indication that they recognize the same word when it is presented in different situations.

Procedure

The present study divided into the following phases:

(1) Construction of a tactual vocoder;

(2) feasibility demonstration of vocoder-plus-training with hearing subjects, artificially deafened during the training sessions; and

(3) preliminary confirmation demonstration of vocoder-plus-training with deaf subjects.

Construction of the Vocoder

The device constructed at Oregon Research Institute (the site of the training experiments) incorporated several new wrinkles, but was not radically different from previous tactual vocoders. The final version used with hearing and deaf subjects employed a 23-channel vocoder. The frequency range from 200 Hz through 4000 Hz was divided into equal logarithmic intervals and transmitted through 15 channels. Four low frequency channels extended the lower range to 85 Hz, and four high frequency channels extended the upper range to 10,000 Hz. The purpose of the low frequency channels was to provide information about fundamental pitch of speech (Flanagan, 1972). The high frequency extension allowed for discrimination of fricatives (sh, ch, s, f), which were not adequately discriminated at the 4000 Hz level for some speakers (Hughes and Halle, 1956; Heinz and Stevens, 1961).

To receive tactual information through the system, a subject attached five metal boxes (each about 3" long) to the surface of his skin (using elastic

bandages to hold the boxes in place and upright). Each box contained solenoids that were activated by the vocoder channels. In all, there were five boxes (3 with five solenoids each, and 2 with four solenoids each). The solenoids in turn were attached to small metal plungers which protruded slightly through the base plate of the boxes. When a solenoid was activated, the plunger pushed against the skin and vibrated. Plungers were spaced one-half inch apart in each box.

Two microphones were attached to the system, so that a trainer could talk into one and the subject could respond into the other. A schematic diagram of the apparatus appears in Figure 1.

Insert Figure 1 about here

Training Hearing Subjects

The hearing subjects were four female instructors employed by the Engelmann-Becker Follow-Through Program at the University of Oregon. All were in their 20's. Training began in September 1972 and terminated in August 1973. Subject 1 received 80 hours of training, Subject 2 received 70 hours, Subject 3 received 50 hours, and Subject 4 received 20 hours.

The basic procedure used in all training sessions was for the trainer to sit next to the subject. The trainer spoke words into a microphone. The subject responded by identifying the word. The subject did not look at the trainer during the word or sentence drill. Furthermore, the subject wore headphones through which was transmitted about 85 dB of white noise, thereby rendering the subject artificially deaf. Since the subject neither looked at the trainer nor was able to hear the trainer, the only source of information about the words presented came through tactual vibration.

Training sessions lasted 20 to 60 minutes (usually 30 minutes). Although there was an attempt to schedule daily sessions, the subjects' university training activities took them out of town regularly, often resulting in absences of one or two weeks at a time in the training.

The training time was divided roughly in the following ways:

Isolated words presented randomly - 70% of available training time. The exchange between trainer and subject followed this pattern:

Trainer: Get ready...fan

Subject: Fan.

Trainer: Yes.

Subject: Yes.

Corrections were handled through the vocoding system, whenever possible, with no face-to-face contact (a procedure that was abandoned if the subject continued to miss the word).

Trainer: Get ready...and.

Subject: Hand.

Trainer: Not hand.

Subject: Not hand.

Trainer: And.

Subject: And.

The immediate correction was followed by a firm up. The purpose of the firm up was both to demonstrate to the subject the difference between the two words that were confused and to provide the investigators with information about the relationship between the subject's ability to perceive minimum differences in words and their ability to remember these differences. To firm the subject, the trainer would randomly present the two words that had been confused (in the example above, and and hand) until the subject could identify 6-10 consecutive words without making a mistake.

Individual words were taken from a master word list (see Table 1). New words were introduced to the subject when she reached a specified criterion of performance on the words that had been previously presented. For two of the subjects, new words were introduced only after they were able to identify 70% of the words in their tactual vocabulary on the first trial (the words were presented in random order). One subject operated from a criterion of 60% first-trial accuracy. One subject operated on an 80% criterion.

Vocabulary words presented in connected sentences - 15% of available time. Sentences constructed from the word list were spoken at a normal speaking rate with no great distortions or emphasis. Words were run together as they are in normal speech, with no artificial pauses to separate them. Although these sentences were not "randomly" constructed, they were low in probability. "She was a sly sister." "Boot mother on Wednesday." "Stand up again, Linda Ycungmayr." "She is not a fan man." "What is a bat?" "Hand me a sister's brother." Particular sentences were not repeated. Rather, the trainer made up different sentences each time sentence practice was introduced.

The procedure for presenting sentences was similar to that used for individual words.

Trainer: Get ready...He has a little man.

Subject: He was a little man.

Trainer: Not was.

Subject: Not was.

Trainer: Has.

Subject. Has.

Trainer: He has a little man.

Subject: He has a little man.

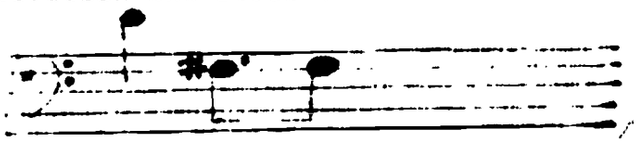
Trainer: Good.

Subject: Good.

In over 90 per cent of the trials on sentence work, no face-to-face contact between trainer and subject was involved. In the remaining 10 per cent, the trainer presented a sign for the word or had the subject look as she said the confused word into the microphone.

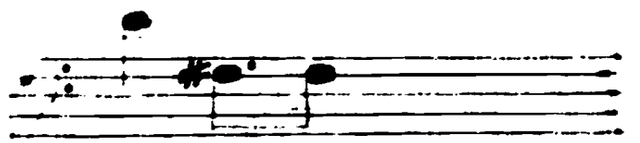
Inflection copying - 5% of the time. The procedure for inflection copying was for the trainer to present a word from the subject's vocabulary with a unique, sometimes melodious inflection. The subject then attempted to match the inflection and stress.

Trainer:



Sat - ur - day

Subject:



Sat - ur - day

The trainer corrected the subject by facing her, then motioning with her hand to make part of the word higher or lower (a technique the investigators recognized would not be effective for deaf subjects who didn't understand the relationship between a spatial "up" and a vocal "up").

Rhyming - 2% of available time. Below is the procedure used for introducing rhyming:

Trainer: Rhymes with and.

Subject: Rhymes with and.

Trainer: Yes.

Subject: Yes.

Trainer: Rhyme with and----------ssssss.

Subject: Rhyme with and----------ssssss.

Trainer: Sand.

Subject: Sand.

Trainer: Good.

Subject: Good

Both rhyming and inflection were introduced to subject only after she had worked on the vocoder for more than 30 hours. For the two subjects who received more than 60 hours of training, rhyming was used to introduce some new words into their vocabulary. It was also used to correct mistakes. For example:

Trainer: Get ready...filly.

Subject: Silly.

Trainer: Rhymes with silly...fff

Subject: Filly.

Face-to-face work - 3% of available time. Initially most of the words were introduced face-to-face. Sometimes the trainer would accompany the word with a sign that signified the meaning (fanning herself to indicate fan, etc.). Later, face-to-face work was used to direct the subjects on inflection copying and rhyming, particularly when isolated sounds such as "rrr" and "mmm" were introduced.

The Word List

The isolated words presented to the hearing subjects and those used to compose the sentences they identified were taken from a list developed according to the following criteria:

(1) The list was to provide information about the subjects' ability to handle words that were minimally different, that is, different in only one phoneme (and-band, we-me, it-is, sly-fly).

(2) The list was to provide a fair sampling of single-syllable words that begin with a consonant sound and those that begin with a vowel sound.

(3) The list was to contain at least a modest sampling of two-, three-, and four-syllable words (to provide some basis for judging the relative difficulty of these words compared with single-syllable words).

(4) Finally, the list was to contain many of the words that would be used in instructions and statement tasks with deaf children (words such as what, is, that, not, touch, why).

This list, consisting of 60 words, appears in Table 1.

Insert Table 1 about here

Performance Tests.

The subjects were regularly tested on the words in isolation. The initial goal was to test them each week, but their travel made such a test schedule impossible. A drop-out design was introduced to distinguish the relative difficulty of the words in the subject's tactual vocabulary. Words were presented in random order. If the subject correctly identified a word on the first "run through" of the list, that word was "dropped" and the subject received a score of "1" (first trial). If the subject misidentified a word, she was told the word; the word was set aside until the end of the first run through. All words not correctly identified on the first trial were then presented in a random order in a second run through. If the subject correctly identified a word on this run through, a "2" was entered on the score sheet for that word and the word was dropped. The procedure was repeated until all words had been correctly identified or until the subject had received three trials.

Results with Hearing Subjects

Results of the test performance with hearing subjects is summarized in Table 2.

Insert Table 2 about here

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(1) Performance is a function of practice. Although the subjects often received no training for periods of two or more weeks at a time, the number of words they identified on first trial generally increased with additional time (practice).

After nine months of practice, Subjects 1 and 2 scored about 90 percent first-trial accuracy on the 60 words (missing only 6 or 7 words and identifying these on the second trial).

(2) The rate of acquisition seems to be associated with the criterion used for introducing new words. The lower the criterion for introducing new words, the faster the subject mastered new words. Subject 4 was on a 60 percent new-word criterion. After two months, she outperformed the other subjects. Subjects 1 and 2, who progressed fairly rapidly, were on a new-word criterion of 70 percent, while Subject 3, who progressed the slowest was on an 80 percent new-word criterion.

(3) Subjects 1 and 2 (who received training for the longest period of time) frequently achieved above 90 percent correct on the first trial when working with the complete list of 60 words. On at least four training sessions both subjects correctly identified 59 of 60 words on the first trial. On more than 10 training sessions, they identified all but two words. (The performance on the test was consistently below their training-session performance, perhaps a function of inadequate "warm up".)

(4) The relative degree of difficulty of different words diminished with training. During the first month of training, 18 percent of the words were not identified after the second trial. After the first two months, however, only one percent of the words were not correctly identified on either the first or second trial.

(5) Related to (4) above is the observation that the more quickly a subject mastered a new word, the better the subject's memory for that word. The data in Table 2 doesn't lend itself to this conclusion because there was a ceiling placed on the subjects' performance. After all 60 words had been introduced, the subjects did not formally work on any new words, thus placing a ceiling on their performance. However, after Subjects 1 and 2 had received over 60 hours of training their trainers would typically invite visitors to select any five new words. These were then presented to the subject. The subject could almost always master all words presented in different orders after a one-trial introduction. A rough estimate is that after 60 hours of training, the subjects could master a set of five words to a "firm" criterion in 1/50th the number of trials required during the first month of training. (This does not mean that the subjects could "remember" the words to identify them in subsequent sessions.)

Identification of words in sentences. Although no data were tabulated on the performance of sentences spoken at a normal rate, the following observations were made by the investigators:

(1) Well over half of the arbitrarily constructed sentences presented to the subjects (and usually made up on the spot) were correctly identified on the first trial, even when these sentences were quite elaborate, such as, "Hand mother and sister a boot on Wednesday."

(2) The most frequently missed word in the sentence was the first word. In longer sentences, the subjects would sometimes fail to identify the last words; however, actual misidentifications did not frequently occur near the end of the sentence. A possible explanation is that the first word of the sentence is presented against a baseline of silence. The word appears suddenly. The remaining words in the sentence, on the other hand, are presented against a baseline of other words. It is therefore easier to compare the

characteristics of these words. A similar phenomenon was observed with words presented in isolation. During the first weeks of the experiment, these words were presented without a "get ready" warning. The errors seemed to drop with the introduction of the "get ready" and a slight pause before presentation of the word.

(3) The performance of the subjects on sentences and the relatively small amount of time devoted to sentence identification seems to imply that the perception of connected speech is "easier" than the perception of individual words.

Copying voice pitch patterns.

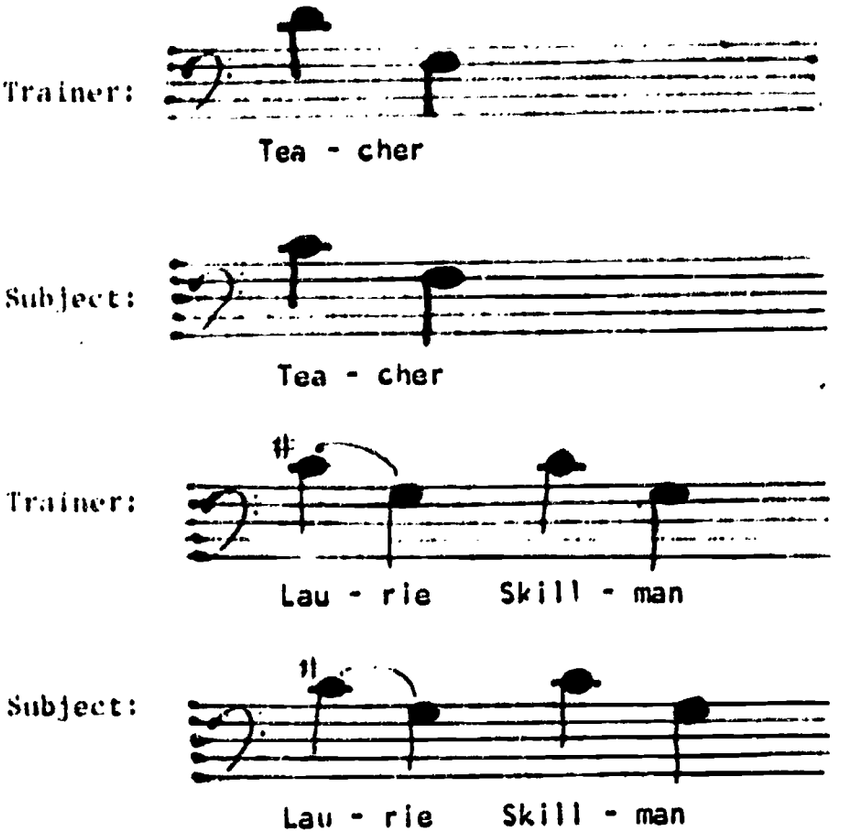
(1) With a minimum of training, Subjects 1 and 2 could not only copy with the relative pitch of a complex pitch pattern, but could imitate the pattern precisely, varying no more than a quarter tone from each produced pitch. This performance was achieved on over 90 percent of the trials in which the subject responded to a female speaker whose voice fell in the same register as the subject's voice. When a male speaker presented pitch samples, the subjects copied the relative pitch (and with diminished accuracy). Samples of Subject 2's pitch performance (transcribed from audio recording) appears below:

Trainer:

Tues - day

Subject:

Tues - day



(2) A minimum degree of facility with the vocoder seems to be required before subjects can perform on pitch discrimination exercises. Attempts to train Subjects 3 and 4 on pitch discriminations after they had received between 12 and 20 hours of instruction produced only modest results. Subjects 1 and 2, however, spontaneously began to match inflections of the trainer after they had received around 60 hours of instruction. Possibly, attention to pitch assumes a familiarity with the other speech variables with are transmitted through the vocoder. This familiarity may be attainable only after so many words or types of words have become familiar.

Performance as a function of placement of vibrators. Subject 2 worked with the vibrators attached to her fingers. The other subjects had vibrators attached to their forearms.

(1) No difference in performance seems to be attributable to the placement of the vibrators since Subject 1 performed at least as well as Subject 2.

(2) Subjects 1 and 4 performed as well when the vibrators were transferred to their legs. The same configuration was maintained (the same relative position of the vibrators), and the transfer was instant. In fact, Subject 4 performed slightly better on all words in her list the first time she worked with the vibrators on her legs. Subject 1's performance was only slightly inferior the first time she responded to the vibrators on her legs. The kind of transfer exhibited by Subjects 1 and 4 would indicate performance observed was a function of mastery of the patterns, not of any neurological adaptation or increased sensitivity of particular body parts. The subjects had learned how to attend to specific details in a complex array. When the array was transferred to their legs, they had no trouble processing the information.

Training Deaf Subjects

In August, 1973, training of the hearing subjects was terminated. With less than 100 hours of intensive training, two of the subjects had mastered difficult phonemic discriminations, had learned to match inflections, were able to handle rhyming tasks with reasonable accuracy, and were able to perceive sentences presented at a normal speaking rate. The investigators judged that deaf subjects would learn the same skills but that they would start from a much lower starting point and therefore would probably proceed more slowly.

In August, work with three deaf subjects began. A fourth subject was added in November 1973. Subjects were young males, each with a bilateral hearing loss exceeding 95 db in the range of 250-8000 Hz.

Subject 1, an eight-year old boy, was quite alert, but was lacking all but the most rudimentary speech behaviors at the beginning of training. He was substantially behind in academic skills and tended to "act out" in school.

Subject 2, a 14-year old boy, was quite verbal and articulate on phrases that are used in everyday exchanges. His verbal performance when reading a

third-grade book, however, was largely incomprehensible at the beginning of training. With his hearing aid, he was able to hear voices and identify some words when he was not facing the speaker.

Subject 3 was a 13-year old boy who had a history of behavior problems. He seemed eager and cooperative, although his speech behavior (as well as written communication skills) were grossly deficient.

Subject 4 was an eight-year old boy who was lacking in all but the most elementary speech behaviors.

Subjects 1, 3, and 4 were prohibited from using hearing aids during training sessions with the tactual vocoder. During most of the experiment Subject 2 was allowed to use the combination of tactual information and what information he could secure through his hearing aid.

Although the procedures used in the training session were similar to those used with hearing subjects, there were differences. Specifically:

(1) Vibrators were placed on the subjects' thighs (three boxes on one thigh, 2 on the other) so that the subjects' hands would be free to touch objects or pictures.

(2) Particularly during the first two weeks of training the subjects responded by touching rather than by producing verbal responses.

(3) Some time was spent during each period to work on articulation (to prepare the children for verbal responses and to break up the period).

(4) Because of the need to teach basic speech skills in connection with the perception of speech patterns, longer periods were introduced (initially one hour a day for six days a week, and later for five days a week).

(5) A reinforcement system was introduced to "turn on" the subjects and keep them on task. Children worked for pennies or nickels. The rules for earning these rewards varied with each child's proficiency.

(6) The emphasis of the training sessions was not on isolated words or

phonemes but on connected sentences. The rationale for this emphasis is that a series of sentences could be presented in such a way that the subject actually had to attend to only part of the sentences. Here are two series that permit selective attention:

(a) Touch the (pause) glass

Touch the (pause) elephant

Touch the (pause) car

Touch the (pause) monkey

(b) Pick up the monkey

Hand me the monkey

I am not a monkey

Is this a monkey

(7) As much as possible, the emphasis of training was on the discrimination of words contained in sentences. The investigators reasoned that the deaf child is typically quite comfortable with "word salad," an indication that he lacks the "syntactical sense" of a hearing subject. Therefore, the goal was to provide the deaf subjects with as much "imprinting" of syntax as possible. To achieve this goal, the various tasks were designed so that all work, including word identification tasks were presented in a syntactical context. Typically after less than a month of training, the trainer introduced this format for word identification tasks.

"Get ready....say the word (pause) glass. Glass."

Later, the "get ready," the pause, and the repetition of the word were dropped from the format: "Say the word monkey."

The subject responded either with the word at the end of the sentence or the entire sentence, "Say the word monkey."

A variety of "phrases" were introduced so that work on word-identification could be conducted in different syntactical contexts. Each subject was taught

five or more phrases, such as, "pick up...," "touch...," "hand me the...," "this is a(n)...," "I am a ..," "this is not a(n)...," "I am not a(n)..." During most of the training sessions, the trainer would present sentences composed of the "words" in the child's tactual vocabulary and the phrases. For example, here is an excerpt from the sixth week of training with Subject 2:

Trainer:	Subject:
Touch the glass.	Touch the glass.
Yes.	Yes.
Pick up the elephant.	Pick up the elephant.
Yes.	Yes.
I am not a glass.	I am not a cow.
Not cow.	Not cow.
Glass.	Glass.
Yes.	Yes.

The Training Sessions

In all work with words and sentences the subject did not look at the trainer. The only information received by the subject was through the vocoder. The trainers tried to correct all mistakes through the vocoder, with no visual contact. This was not always possible during the early sessions but became increasingly manageable as the subjects attained greater skill.

Below is a description of each of the activities presented during the training sessions and a brief rationale for each.

(1) Face-to-face work on articulation (15% of available training time). The investigators were faced with a difficult trade-off in terms of showing results with the vocoder. Perhaps the greatest potential of the system lies in the area of helping a deaf child speak in a conventionally acceptable manner.

The subject's ability to use feedback about the details of speech is limited by the subject's capacity to "hear" or perceive these details. If the

subject cannot "hear" the difference between the "s" sound and the "sh" sound, he is pre-empted from "matching" the "s" sound produced by the trainer. The perception of speech is a prerequisite to sophisticated articulation training; therefore, the investigators established speech perception as the highest priority.

The content of the face-to-face articulation work varied with each child. The rule followed by the trainers was this: If the child is to give a verbal response to any of the tasks you present, work on the articulation of those responses. Make sure that the subject can produce an acceptable, if not perfect, response. Limit the amount of time spent on face-to-face work to no more than 8 minutes a session.

The initial face-to-face work concentrated on the production of basic sounds. For example, Subject 1 initially could not say words beginning with an "m" sound. He stopped the "m," saying "mmbe" instead of "me". Subject 2 had a similar problem with"s" saying "s(t)itting" instead of "sitting". Later face-to-face work focused on more advanced skills, such as saying a sentence without stopping between each word, for example, saying, "Iamuman," rather than "Iyn amm oay monn."

(2) Words and sentences--(65% of available time) As noted above, the goal was to introduce words in a syntactical context as early as possible. Because of the management and articulation problem that obtained during the first days of training, however, the trainers had to present a series of "touching tasks." A display of three or more objects was placed in front of the child. The trainer sat slightly behind the child so that he could not see her face.

Trainer: Get ready....touch the (pause) monkey...Monkey.

The child was not required to produce a verbal response. He was required simply to touch the appropriate object. After perhaps 6 hours of training a

format requiring a verbal response from the child was introduced.

Trainer: Get ready...touch the (pause) monkey...Monkey.

The child was now required to touch the appropriate object and say the appropriate name, "Monkey."

As part of the work on words and sentences the children were tested at least twice a week. A test consisted of the presentation of all the words in the child's vocabulary. Words were presented one time in random order. Trainers recorded the first-trial for each word. During the tests, the words were presented in sentence contexts, using a format familiar to the child. However, the same phrase was used with all the words tested. For example, all words would be preceded by "this is a(n)...." for a given test. For the next test, all words might be preceded by "say the word...." The convention of using the same phrase for all words was introduced to simplify the recording of data.

(3) Isolated sounds and rhyming: 10% of available time. During the early training sessions, work with letter identification was implemented with Subjects 1, 3, and 4. The children identified letters by their sound (the letter) "s" being identified as "ssss" for example).

Deaf subjects who received training for at least 20 weeks were introduced to rhyming tasks. The format for these tasks was the same as the format for the hearing subjects.

Trainer:	Rhymes with at.	Subject:	Rhymes with at.
	rrrrrr.....		rrrrrr.....
	rrat...		rrat...
	good.		good.
	Rhymes with at		Rhymes with at
	sss...		sss...
	etc.		

The rationale for work with rhyming was that it could be a useful source of information about the individual sounds within words (and that the words are composed of individual and different sounds). The rhyming tasks rarely

exceeded 4 minutes during a session and usually involved the presentation of these sounds: "rrr," "mmm," "sss," "shhh," "c," and sometimes "lll".

(4) Language-action tasks: 10% of available time. The work with language action tasks involved a less structured use of language. The trainer would present tasks from a book. The subject was not prohibited from looking at the trainer; however, the trainer pointed to illustrated matter on the page and often presented tasks while the child was looking at the page. The trainer would typically present tasks such as:

"What is this?.....Is this a man?.....Say the whole thing.....What is the girl doing?.....Say the whole thing.....Is the girl sleeping?.....Is the girl riding a horse?.....Is the girl sitting?.....Is she climbing a tree?....."

The child was not required to repeat the questions presented by the trainer; however, from time to time the trainer would follow a question by saying, "What did I say?" The child received points for correct responses.

Language-action tasks comprised as much as 20 per cent of the early training periods. They were used as a "change of pace" to reduce the high degree of concentration required by the word identification tasks. After the children had been in the training program for 15 weeks the language-action tasks assumed a position of less prominence. On many days, they were not presented at all (particularly on test days, when the list of words became quite long); however, these tasks were often used as rewards for a good performance.

The Word Lists

Each child worked from a slightly different word list, and none of the lists was identical to that used by the hearing subjects. The lists were "individualized" according to a) the individual child's ability to articulate different sounds; and b) the investigators' manipulation of discriminations within the vocabulary, so that assessments of the child's learning rate, retention, knowledge of individual

sounds, etc., could be evaluated.

As a rule, words were not presented unless the subject was able to articulate the word in such a way that it would not be confused with any other word in the child's tactual vocabulary. During different phases of the work with deaf subjects, the investigators introduced difficult words, in an attempt to see how long it would take the subject to master these, whether they had a deteriorating effect on the other words the child had mastered, whether their introduction facilitated the child's ability to generalize to new words, and whether more practice was required for these words or for words presented at the beginning of the program.

For example, by the 22nd week of training, subject one had 37 words in his vocabulary. Among these words were she and mother. During the next week, the following words were introduced: see, brother, other, bat, rat and fat. The investigators observed the effect the introduction of these words had on the child's performance.

During most of the training, the trainers followed a performance formula for introducing new words. The formula was based on 70-80 per cent first-trial performance. If a child's performance level fell below 70 per cent, the trainer dropped words in the vocabulary and firmed the remaining words. When the first-trial performance exceeded 80 per cent, the trainer introduced new words and integrated these with the others in the child's vocabulary.

Reinforcers

Positive reinforcers were used with all subjects on sentence identification tasks. The reinforcement schedule varied according to the task presented and to an individual child's behavior. Initially, all children received one point for every correct response. After earning 10 points, the child received a penny or a nickel. If children developed a pattern of guessing, the schedule was changed so that the child had to make so many consecutive correct responses before earning a nickel

or a penny. At the end of each training period, the child was given an opportunity to purchase items that had been placed in the "store," or he was allowed to keep the money.

Initially, no points or money were awarded for face-to-face work. Later, contingencies were introduced so that the child was reinforced for performing acceptably on words or phrases that had been practiced in face-to-face work. For example:

Trainer: Get ready. (pause) Touch the glass.

Subject: Touch...the...glass.

Trainer: Good.

Trainer awards two points to the child and says face-to-face, "Two points. You said glass. So I gave you a point for good talking."

Results and Discussion

Subjects were tested weekly on words in isolation. The results of their first trial performances are summarized in Table 3. The data for the table had been obtained after Subject 1 had received 36 weeks of training (approximately 160 hours) and the other subjects had received less training (ranging down to 12 weeks for Subject 3). As Table 3 shows, the performance of the deaf subjects is similar to that of the hearing subjects, although perhaps slightly slower during the first month of training. Like the hearing subjects, a) performance improves with practice, b) the relative difficulty of words decreases with practice, and c) subjects were consistently able to maintain first-trial accuracy of 70 per cent or better even as their tactual vocabulary expanded.

Insert Table 3 about here

Since each subject worked from a slightly different vocabulary, the

performance for each subject is presented individually.

Subject 1: Subject 1's first-trail word-identification performance over 36 weeks of training is summarized in Figure 2. The top of each bar indicates the number of words in his vocabulary. The shaded part of each bar indicates the number of words correctly responded to on the first trial.

Insert Figure 2 about here

The performance of Subject 1 is more variable than that of any hearing subject. This performance variability was at least partially caused by experimental manipulation, particularly during the weeks 23-26. Twelve difficult words were introduced during these weeks.

It is difficult to say whether Subject 1 learned as rapidly as the hearing subjects. His training sessions lasted one hour, compared with the half-hour sessions for the hearing subjests. At the end of 14 weeks, Subject 1's vocabulary consisted of 27 words. All hearing subjects had vocabularies of more than 27 words by the end of the 14th week of training. One hearing subject had 27 words at the end of one month; another had 35 at the end of two.

The rate of deaf Subject 1's mastery, however, is impressive, particularly beginning with the 31st week of training. During weeks 32 through 35, twenty-seven new words were introduced. Performance on these words (as well as the others in his vocabulary) is maintained at 75 per cent or above. In contrast to this performance, mastery of the first 27 words in the program had required 14 weeks of practice. In calendar time, the rate of mastery increased 3.5 times over the initial rate. The saving in number of trials is even more dramatic. When the first 27 words were introduced, these were the only words the child practiced during the training sessions. Mastery of these words required approximately

14,000 trials, compared to less than 1400 for the 27 newest words added during weeks 32-35. Also, the type of discrimination required for the latter task is more difficult, since the child not only had to identify the 27 new words but had to distinguish between them and other similar words in the vocabulary. For example, a word such as sit (introduced in week 34)could have been confused with sat, fat, see, and five other words that began with s. This task is theoretically more difficult than the task in week 12, when the first s-beginning word (sister) was introduced. The probability of confusing sister with similar words was not as great because there weren't as many similar words in the list.

Subject 1's performance on five new words presented during the 34th week of instruction is summarized below by trials. The words were:eat, go, jump, give put. The five words were presented in random order until the child achieved two consecutive perfect runs. Then the words were randomly integrated with 16 familiar words and again presented until the child achieved two perfect runs.

First, the five-word set:

Trial 1 5/5

trial 2 3/5

trial 3 5/5

trial 4 5/5

Then the five words when randomly interspersed with 16 familiar words:

Trial 1 5/5

trial 2 4/5

trial 3 5/5

trial 4 5/5

The rate at which Subject 1 was capable of learning matched or excelled that of hearing Subjects 1 and 2.

Subject 2: Figure 3 summarizes the performance of Subject 2 on first-trial correct identification for his 26 weeks of participation in the experiment. The heavy vertical lines on the figure mark the period during which the subject did not wear his hearing aid (weeks 9-17). During the remaining weeks (1-8 and 18-26) Subject 2 used his hearing aid and the vocoder during the training sessions.

Insert Figure 3 about here

Subject 2 progressed quite rapidly during the first eight weeks of training. When he was prohibited from using his aid, he virtually had to start over. His rate of progress without the aid, however, seemed reasonable. By the end of the sixteenth week, his vocabulary consisted of 24 words, only four less than Subject 1's vocabulary at this time.

With the reintroduction of the hearing aid, Subject 2 progressed rapidly, particularly during weeks 23 and 24. Twenty-nine words were added to his vocabulary during these weeks, while his performance consistently remained at or above 70 per cent.

The extent to which the subject relied on information received through his hearing aid is not easy to determine. What seemed to have happened during the training was that the subject became more proficient at "hearing" the training words through his aid. When tested during the 8th week he performed at about 65 per cent accuracy in response to training words when he used only his hearing aid (not using the vocoder and not looking at the trainer). His performance with only the vocoder was about 40 per cent accuracy on the same words. His performance when both the vocoder and aid were used was about 94 per cent. The investigators were quite surprised, however, to find that the subject's performance on common

words not in the vocabulary was only about 20 per cent accuracy when the subject used the hearing aid only. The conditions were the same as those used to test the training words. Apparently, however, the subject learned to "hear" or to use his hearing aid with far more precicion than he had in the past. Perhaps the repetition and focus provided during the training sessions taught the child to attend to information to which he had not previously attended.

Subject 2 was dropped from the experiment after the 26th week, at which time he was able to perform acceptably with a vocabulary of 95 words. The primary reason for dropping him was that the training sessions were conflicting with other activities in which the subject wanted to participate.

Subject 3: Figure 4 shows the performance of Subject 3 on first-trial accuracy. At the end of the 12th week his word list consisted of: elephant, cow, monkey, glass, chair, shoe, book, table, tape recorder, Rodney, paper, light, sister, m and m, ashtray. The performance of this subject is slower than that of the others. During a two week period, he was not available for training and during most of the experimental period (12 weeks) he was experiencing a number of personal problems. The investigators make no assumptions about the extent to which these affected his performance, except that they resulted in frequent absences.

Insert Figure 4 about here

Subject 3's rate of progress during the first four weeks was as rapid as that of Subject 2 and surpassed that of Subject 1. Subject 3's performance deteriorated somewhat following a two-week absence from the training; however his performance was not substantially behind that of Subject 1 at the end of the 12th week (at which time Subject 3 withdrew from the experiment).

Subject 4: As Figure 5 indicates, the first trial performance of Subject 4 improves more slowly than that of the other deaf subjects. During the 29th week of training, Subject 4's vocabulary consisted of only 36 words, compared with 53 for Subject 1. The reason for the relatively slow progress of Subject 4 is not apparent. During the sixteenth week new training and firming procedures were introduced and Subject 4 apparently had trouble adjusting to these. At that time, the number of words in his vocabulary was reduced from 29 to 22 and the child required eight weeks before the number of words exceeded thirty. The progress from the seventeenth week on was relatively stable although not rapid. At the end of the 29th week, Subject 4 was able to learn new words quite fast, although not as rapidly as Subject 1. To master five new words, Subject 4 required six run throughs or 30 trials. The trainers suggest that Subject 4's major problem seems to be his memory. He learns quickly but has some difficulty remembering words from day to day.

Insert Figure 5 about here

Conclusions

(1) Deaf subjects can be taught to hear fine speech discriminations through the tactual mode.

(2) The performance of subjects is positively correlated with practice and seems to be clearly a function of training.

(3) The quest for the appropriate tactual display of speech therefore, must be conducted within the training context. The adequacy of a display is evident only after sufficient training has been provided.

(4) Hundreds of corrected repetitions are required for either a deaf or hearing subject to learn simple tactual discriminations.

(5) The subject's memory and ability to discriminate increases as the number of words he has mastered increases.

(6) Initially deaf subjects learn more slowly than hearing subjects; however, their rate seems to match that of hearing subjects once an initial set of perhaps 30 words is reliably mastered.

(7) The rate at which a subject is able to learn new words increases with the number of words the subject has mastered (a relationship that cannot obtain indefinitely but which is apparent during perhaps the first year of instruction and probably will obtain for a longer period).

(8) Deaf subjects as well as hearing subjects are able to attend to prosodic features of speech including stress and pitch when speech is presented tactually.

(9) Perception of sentences is no more difficult for the hearing and deaf subjects than perception of isolated sounds or individual words.

The investigators feel that the tactual experiment is important. It provides a unique glimpse into the amount and type of practice needed for a person to learn to use a new sensory modality. It brings issues of neurology and training dogma into sharp focus, with the proof being the performance of the deaf children.

With more sophisticated hardware than that used in the present experiment, streamlined and miniaturized, the deaf infant could learn to "hear" using tactual input in exactly the same way the hearing child learns to hear. It would seem that both would progress as normal "hearing" children, with the babbling, speech behavior and imitation patterns of normal hearing children.

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Footnotes

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TABLE 1

Training Word List*

Notes: *Words are organized as minimal groups such that one phoneme is different among single syllable words, and one syllable is different in two syllable words.

C = consonant

V = vowel

One Syllable

CVC			CV		VVV	VC
boot	fan	has	he	no	why	it
that	pan		she		wow	is
bait	man		me	shoe		
rat			the			
touch	good					
teach						
	live			VV		
this	give		we			

VVC	CCV	VCC	CVCC	V
what	yes	fly	and	hand	a

Two Syllables

again	father	Sunday	silly
	mother	Monday	filly
little	other	Tuesday	
	brother	Wednesday	
stand up		Thursday	
	sister	Friday	
sit down	mister		
batman	teacher		

Four Syllables

(S's name)
/bədi bədi/

Three Syllables

concentrate Saturday

TABLE 2

First Trial Performance For Four Hearing Subjects on Words in Isolation

	Hearing Subjects			
	Subject 1	Subject 2	Subject 3	Subject 4
Training Month				
9	$\frac{54}{60}$ = 90%	$\frac{53}{60}$ = 88%		
8	$\frac{48}{60}$ = 80%	$\frac{46}{60}$ = 77%		
7	$\frac{50}{60}$ = 83%	$\frac{51}{60}$ = 85%	$\frac{38}{45}$ = 84%	
6	$\frac{56}{60}$ = 93%	$\frac{49}{59}$ = 83%	$\frac{30}{40}$ = 75%	
5	$\frac{31}{45}$ = 69%	$\frac{29}{41}$ = 71%	$\frac{26}{39}$ = 67%	
4	$\frac{22}{27}$ = 81%	$\frac{25}{27}$ = 92%	$\frac{20}{29}$ = 69%	
3	$\frac{23}{27}$ = 85%	$\frac{25}{27}$ = 92%	$\frac{18}{27}$ = 67%	
2	$\frac{22}{27}$ = 81%	$\frac{13}{22}$ = 59%	$\frac{7}{13}$ = 54%	$\frac{25}{35}$ = 71%
1	$\frac{14}{27}$ = 52%	$\frac{13}{22}$ = 59%	$\frac{4}{13}$ = 31%	$\frac{16}{22}$ = 73%

Numerator = number of words correct on first trial

Denominator = total number of words in subject's tactual vocabulary

TABLE 3

First Trial Performance For Four Deaf Subjects on Words in Isolation

	Deaf Subjects			
	Subject 1	Subject 2	Subject 3	Subject 4
Training Week				
36	$\frac{70}{81}$ = 86%			
35	$\frac{61}{81}$ = 75%			
34	$\frac{62}{76}$ = 80%			
33	$\frac{52}{66}$ = 79%			
32	$\frac{46}{60}$ = 77%			
31	$\frac{41}{54}$ = 76%			
30	$\frac{35}{53}$ = 66%			
29	$\frac{19}{53}$ = 36%			$\frac{29}{36}$ = 81%
28	$\frac{42}{53}$ = 79%			$\frac{26}{34}$ = 76%
27	$\frac{48}{53}$ = 90%			$\frac{28}{34}$ = 82%
26	$\frac{20}{49}$ = 41%	$\frac{74}{95}$ = 78%		$\frac{26}{31}$ = 84%
25	$\frac{22}{45}$ = 49%	$\frac{69}{92}$ = 75%		$\frac{23}{32}$ = 72%
24	$\frac{23}{43}$ = 53%	$\frac{63}{89}$ = 70%		$\frac{21}{27}$ = 78%
23	$\frac{18}{43}$ = 41%	$\frac{57}{79}$ = 72%		$\frac{23}{27}$ = 85%
22	$\frac{29}{37}$ = 78%	$\frac{43}{60}$ = 72%		$\frac{20}{27}$ = 74%
21	$\frac{18}{36}$ = 50%	$\frac{53}{59}$ = 90%		- - -
20	$\frac{23}{36}$ = 63%	$\frac{44}{50}$ = 88%		$\frac{21}{27}$ = 78%
19	$\frac{21}{36}$ = 58%	$\frac{53}{62}$ = 86%		$\frac{15}{24}$ = 63%
18	$\frac{21}{34}$ = 61%	$\frac{24}{35}$ = 69%		$\frac{18}{22}$ = 81%
17	$\frac{22}{29}$ = 75%	- - -		$\frac{13}{22}$ = 59%
16	$\frac{23}{28}$ = 82%	$\frac{12}{17}$ = 71%		- - -
15	$\frac{26}{28}$ = 93%	$\frac{19}{22}$ = 86%		$\frac{22}{29}$ = 76%

Table 3 (continued)

	Deaf Subjects			
	Subject 1	Subject 2	Subject 3	Subject 4
Training Week				
14	$\frac{25}{27}$ = 92%	$\frac{17}{19}$ = 89%		$\frac{22}{24}$ = 92%
13	$\frac{19}{21}$ = 90%	$\frac{12}{18}$ = 67%		$\frac{22}{24}$ = 92%
12	$\frac{18}{19}$ = 95%	$\frac{12}{18}$ = 67%	$\frac{13}{15}$ = 86%	$\frac{21}{22}$ = 95%
11	$\frac{11}{16}$ = 69%	$\frac{12}{13}$ = 92%	$\frac{12}{15}$ = 80%	$\frac{16}{22}$ = 73%
10	$\frac{15}{16}$ = 94%	$\frac{4}{10}$ = 40%	$\frac{15}{15}$ =100%	$\frac{16}{20}$ = 80%
9	$\frac{12}{15}$ = 80%	$\frac{8}{10}$ = 80%	$\frac{12}{15}$ = 80%	$\frac{13}{14}$ = 93%
8	$\frac{12}{14}$ = 86%	$\frac{33}{35}$ = 94%	$\frac{8}{12}$ = 66%	$\frac{10}{13}$ = 77%
7	$\frac{7}{11}$ = 63%	$\frac{32}{35}$ = 91%	- - -	$\frac{9}{13}$ = 69%
6	$\frac{8}{8}$ =100%	$\frac{16}{23}$ = 70%	- - -	$\frac{6}{9}$ = 67%
5	$\frac{3}{6}$ = 50%	$\frac{9}{12}$ = 75%	$\frac{11}{12}$ = 91%	$\frac{7}{7}$ =100%
4	$\frac{4}{6}$ = 67%	$\frac{9}{12}$ = 75%	$\frac{9}{12}$ = 75%	$\frac{5}{7}$ = 71%
3	$\frac{3}{6}$ = 50%	$\frac{9}{10}$ = 90%	$\frac{8}{8}$ =100%	$\frac{4}{6}$ = 67%
2	$\frac{2}{4}$ = 50%	$\frac{7}{8}$ = 88%	$\frac{7}{7}$ =100%	$\frac{3}{5}$ = 60%
1	$\frac{3}{3}$ =100%	$\frac{2}{3}$ = 67%	$\frac{5}{5}$ =100%	$\frac{2}{4}$ = 50%

Numerator = number of words correct on first trial

Denominator = total number of words in subject's tactual vocabulary

Figure Captions

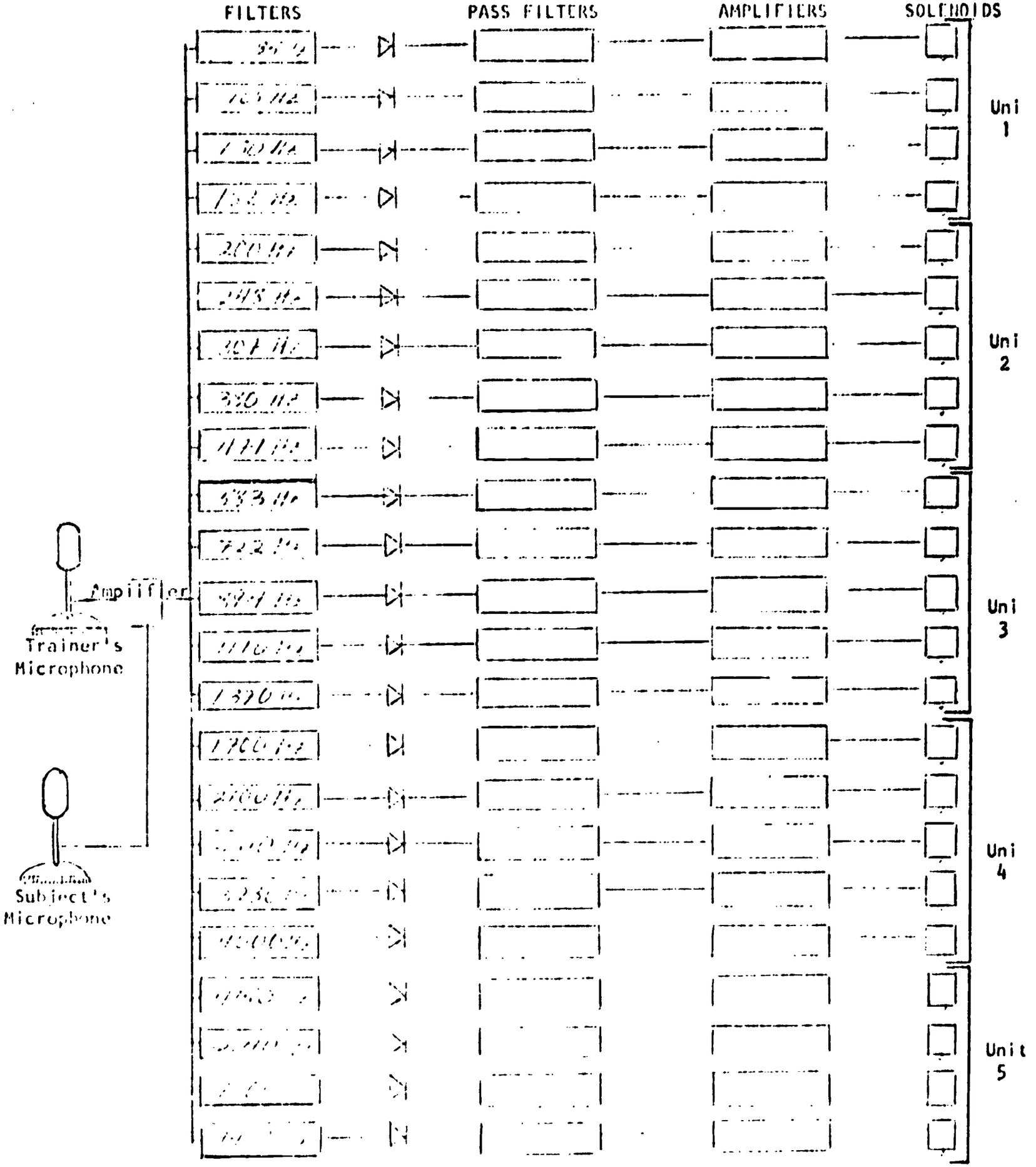
Figure 1. Tactual Vocoder Schematic

Figure 2. Firs. Trial Word Identification Performance for Deaf Subject #1.

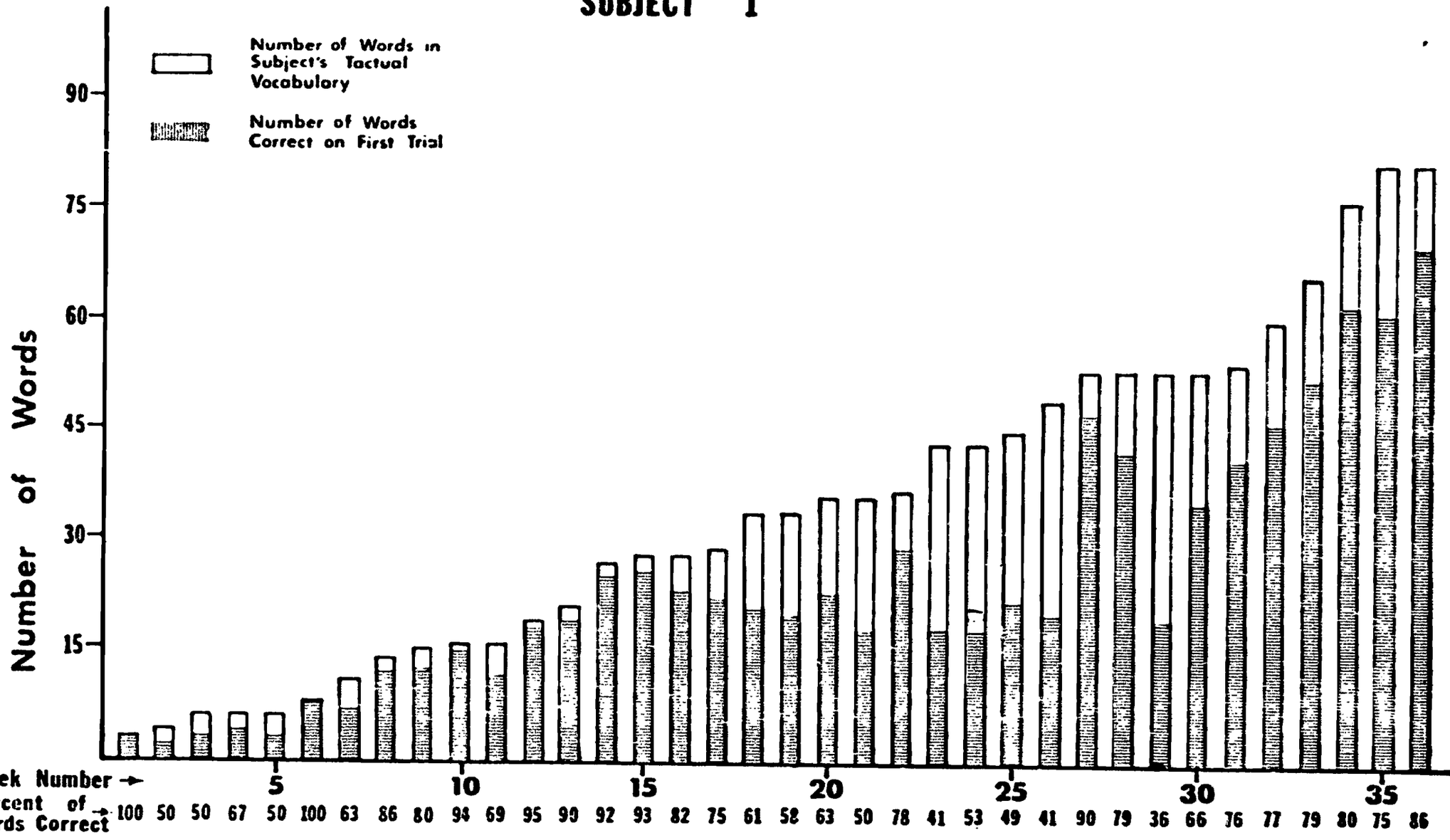
Figure 3. First Trial Word Identification Performance for Deaf Subject #2.

Figure 4. First Trial Word Identification Performance for Deaf Subject #3.

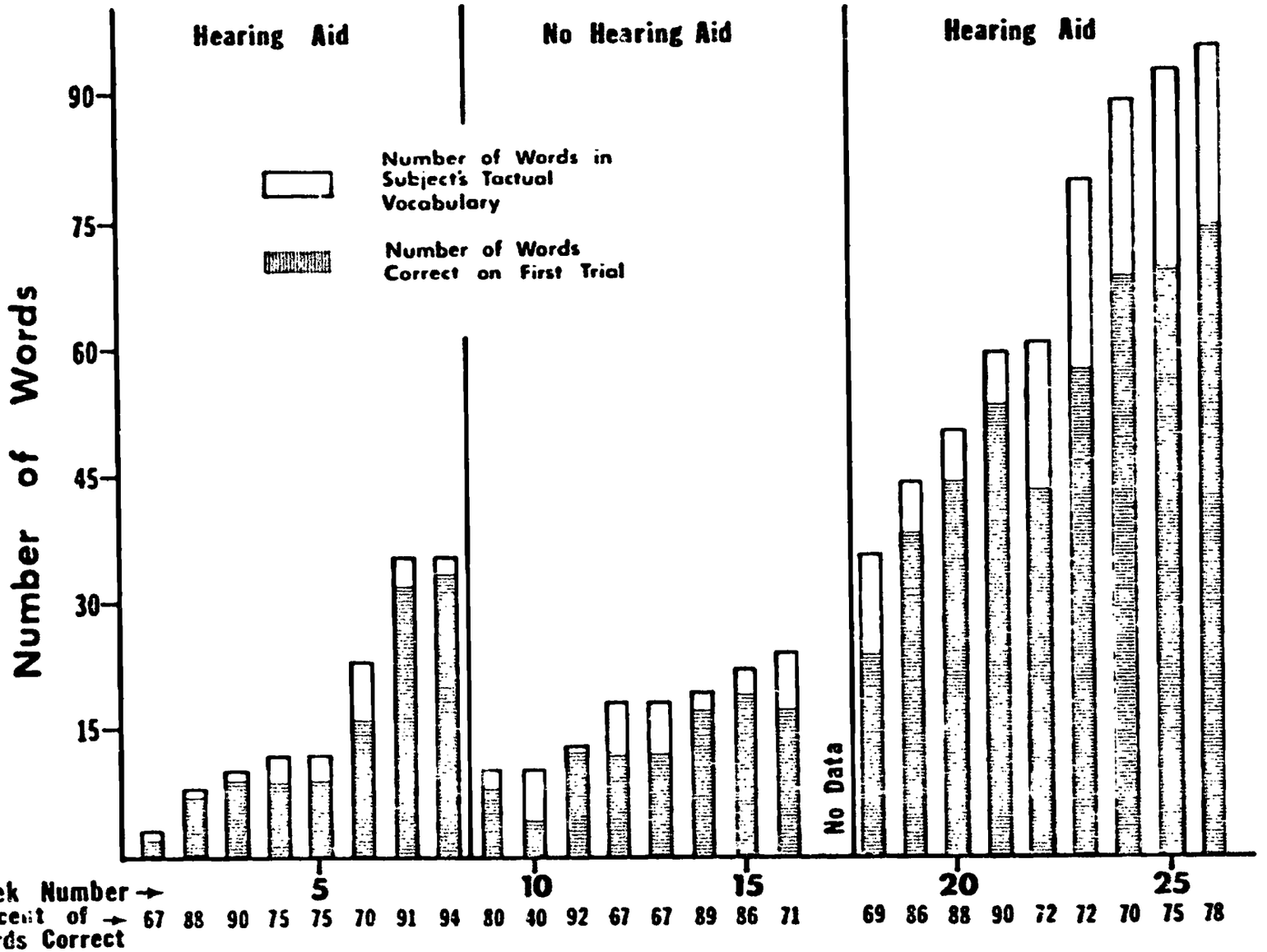
Figure 5. First Trial Word Identification Performance for Deaf Subject #4.



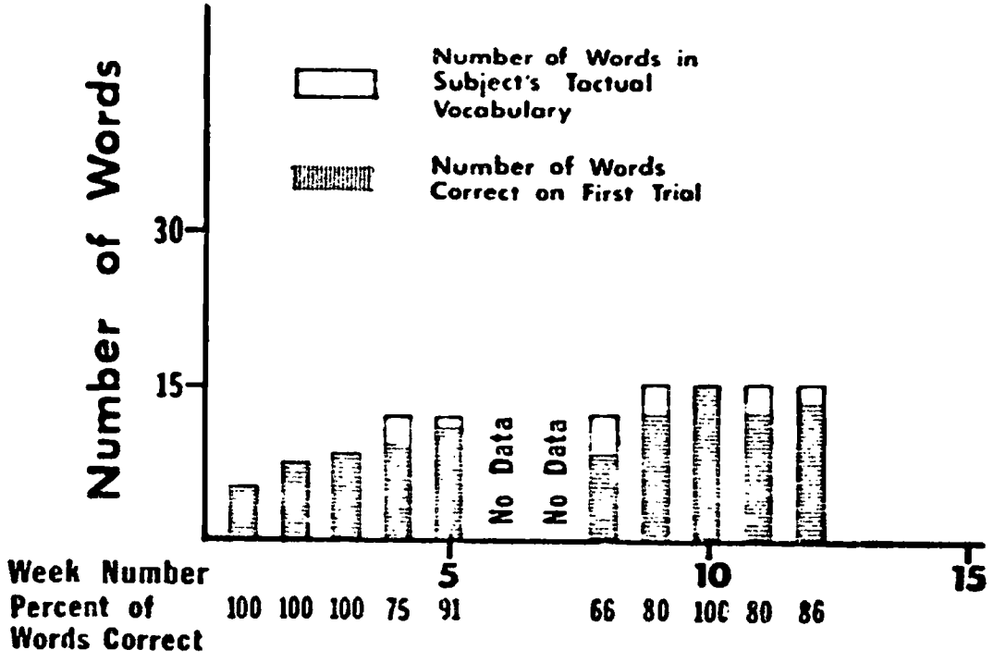
SUBJECT 1



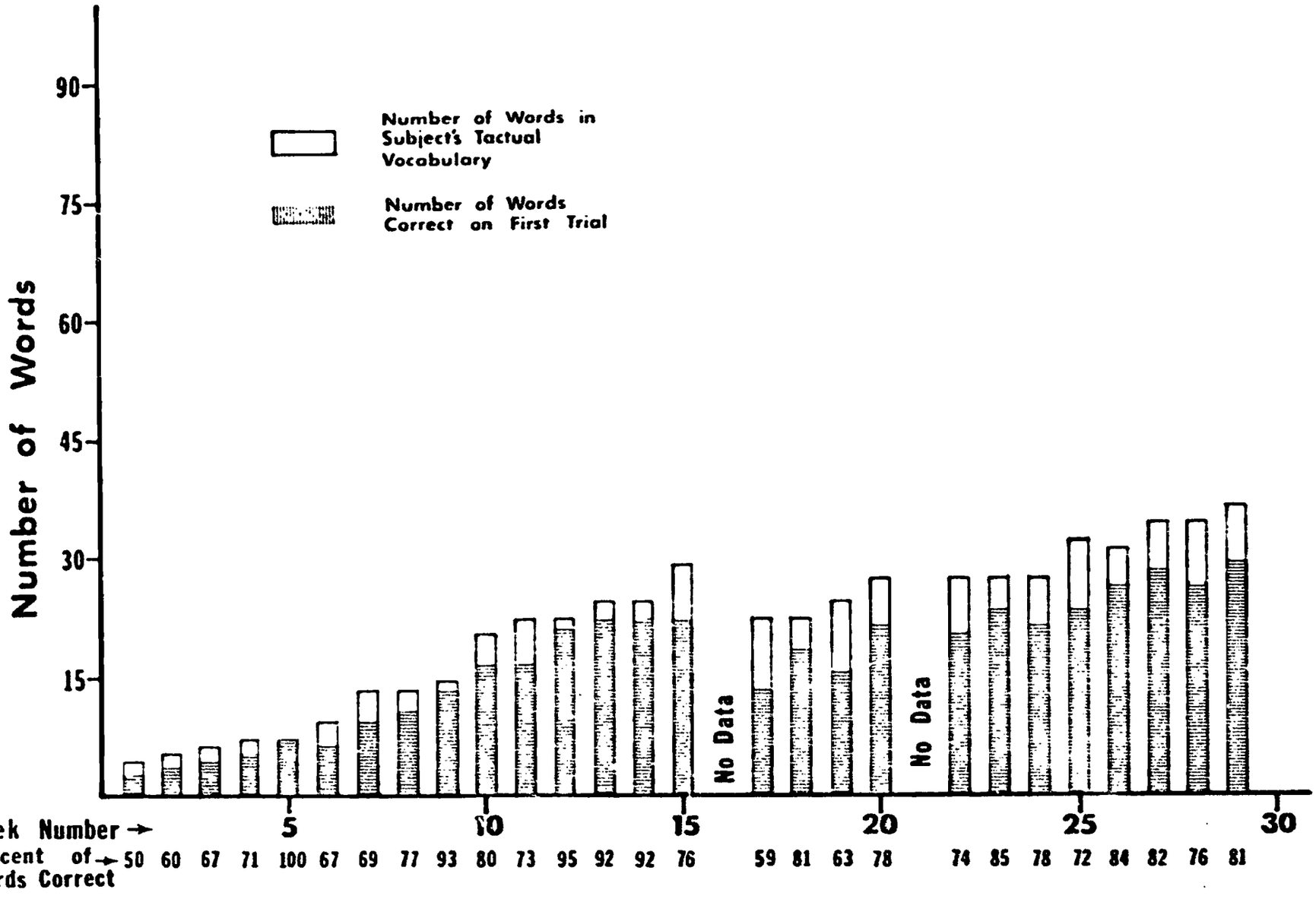
SUBJECT 2


Hearing Aid
No Hearing Aid
Hearing Aid
Number of Words in Subject's Tactual Vocabulary
Number of Words Correct on First Trial
Number of Words
90
75
60
45
30
15
No Data
Week Number →
5
10
15
20
25
Percent of Words Correct →
67 88 90 75 75 70 91 94 80 40 92 67 67 89 86 71 69 86 88 90 72 72 70 75 78

SUBJECT 3


Number of Words
30
15
Number of Words in Subject's Tactual Vocabulary
Number of Words Correct on First Trial
No Data
No Data
Week Number
5
10
15
Percent of Words Correct
100 100 100 75 91 66 80 100 80 86

SUBJECT 4


Number of Words in Subject's Tactual Vocabulary
Number of Words Correct on First Trial
Number of Words
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No Data
No Data
Week Number →
5
10
15
20
25
30
Percent of Words Correct →
50 60 67 71 100 67 69 77 93 80 73 95 92 92 76 59 81 63 78 74 85 78 72 84 82 76 81

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