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Evaluation of a Voice Recognition System for the MOTAS Pseudo Pilot Station Function

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SUMMARY

The Langley Research Center has undertaken a technology development activity to provide a capability, the Mission Oriented Terminal Area Simulation (MOTAS), wherein terminal area and aircraft systems studies can be performed. An experiment was conducted to evaluate state-of-the-art voice recognition technology and specifically, the Threshold 600 Voice Recognition System to serve as an aircraft control input device for the MOTAS Pseudo Pilot Station function. The results of the experiment using ten subjects showed a recognition error of 3.67 percent for a 48-word vocabulary tested against a programmed vocabulary of 103 words. After the ten subjects retrained the Threshold 600 system for the words which were misrecognized or rejected, the recognition error decreased to 1.96 percent. The rejection rates for both cases were less than 0.70 percent. Based on the results of the experiment, voice recognition technology and specifically the Threshold 600 Voice Recognition System were chosen to fulfill this MOTAS function.

INTRODUCTION

The Langley Research Center (LaRC) has undertaken a technology development activity to provide a capability, the Mission Oriented Terminal Area Simulation (MOTAS), wherein terminal area and aircraft systems studies can be conducted. MOTAS is a flexible, comprehensive simulation of the airborne, ground-based, and communication aspects of the terminal area environment. The airborne aspects will include advanced flight deck simulators such as the Terminal Configured Vehicle (TCV) simulator (ref. 1) and the Advanced Concepts Simulator, a full workload DC-9 simulator, general aviation simulators (business jet and light twin classes), computer-generated aircraft with simplified dynamics flown either completely by the computer or through the use of pseudo pilot stations, and LaRC's TCV B-737 aircraft flying at the Wallops Flight Center. The ground-based aspects of MOTAS include air traffic control (ATC) techniques, such as metering and spacing algorithms or vectoring algorithms, control options (speed control, alternate paths, etc), IFR separation standards, navigational aids, terminal area geometrics and air-route structuring, runway handling constraints, and surveillance errors. The communications aspects reflect communications by live ATC controllers and aircraft crews, and communications by computer modelled ATC controllers and aircraft crews. In the cases of the computer modelled ATC controllers and aircraft crews, the communications include such aspects as message content, delays associated with message delivery, delays associated with workload, and priority delivery of messages.

This paper deals specifically with the evaluation of technology and equipment obtained to perform the function of the MOTAS Pseudo Pilot Stations. The Pseudo Pilot Stations are used to make control inputs to computer-generated aircraft in the MOTAS simulation. These aircraft have simplified flight dynamics, and the control inputs consist of commands such as TURN RIGHT, TURN LEFT, HEADING, ALTITUDE, AIRSPEED, TURN DIRECT TO, and so forth, followed by numerical values or waypoint names. In deciding on the type of equipment to be used for this function, several consultations were held with personnel at the Federal Aviation Administration (FAA) Technical Center. The FAA Technical Center operates a simulation facility (ref. 2) similar in concept, although much larger, to the MOTAS simulation. One part of the FAA facility is made up of 64 Pseudo Pilot Stations (fig. 1), any one of which can handle between five and eight aircraft simultaneously depending on maneuvering conditions. At present, the MOTAS configuration plan calls for four Pseudo Pilot Stations, one for each control sector which has been modelled. The FAA Technical Center's Pseudo Pilot Stations are made up of a special purpose keyboard and CRT display (fig. 2). It became apparent early on in the discussions with FAA Technical Center personnel, that LaRC personnel would be faced with training and skill retention problems if this type of equipment and procedures were used. This type of equipment would require learning code words representing waypoints, commands, and so forth, learning the nonstandard keyboard, and learning data input procedures. FAA experience showed that it took some time to learn the system and that practice was required to maintain the skills learned. This would be a definite problem for

the MOTAS Pseudo Pilot Stations since there would be extended breaks of time between MOTAS studies, and thus, a high probability of forgetting and losing skills acquired in training.

Toward the end of these consultations, a possible alternate method was suggested. This method made use of voice recognition technology which was under study (ref. 3) at the FAA Technical Center by another researcher. The goal of the study was "to assess the state-of-the-art in recognition of the spoken word by means of computer technology in order to evaluate its potential usefulness in operational air traffic control". Here the researcher's problem was that "the keyboard language that must presently be used to communicate these data to the computer system is artificial, encoded, almost absolutely inflexible, difficult to learn and remember, subject to error, and a source of distraction to the user". This is exactly the situation encountered with the MOTAS Pseudo Pilot Station concept. The FAA's research indicated that the state-of-the-art in voice recognition technology had advanced to where it might be used to solve this type of problem. Further discussions with the FAA resulted in a recommendation to LaRC to acquire a specific voice recognition device for evaluation which appeared to meet the MOTAS requirements and was still reasonable in cost. The FAA had extensively tested an earlier model of the recommended voice recognition device.

EQUIPMENT DESCRIPTION

In May 1980, LaRC took delivery of a Threshold 600 Voice Recognition System (refs. 4, 5, and 6) manufactured by Threshold Technology, Inc., of Delran, New Jersey. The following paragraph is the manufacturer's description

(ref. 4) of the subject system.

The Threshold 600 system is an electronic speech recognition device which automatically recognizes spoken words or phrases. These words or phrases are referred to as utterances and may be up to two seconds in duration. The utterances must be separated from each other by a very short pause. This is referred to as isolated or discrete speech. The terminal will accept extremely short pauses between utterances; however, the parameters of the human speech production mechanism dictate that pauses between utterances will be typically no less than 0.1 seconds. The terminal accepts utterances as short as 0.1 seconds. Typical spoken utterances will range from 0.25 seconds to 1.0 seconds. The processing time required by the terminal to recognize a spoken utterance will vary depending upon the size of vocabulary implemented in the hardware, but will typically be approximately 0.25 seconds. This processing will begin at the completion of an utterance, and the next utterance can begin before this processing is complete. A READY indicator light is provided to indicate when the terminal is ready to accept an utterance.

The Threshold 600 system (fig. 3) delivered to LaRC consists of an analog speech preprocessor, an LSI-11 microcomputer and a digital input/output interface, an Ann Arbor Model 400E CRT terminal with keyboard for input and display purposes, an operator console and microphone preamplifier, and a tape cartridge unit. The speech preprocessor, microcomputer, and all interfacing elements are contained in the main terminal unit. Details on programming, training, and operating the Threshold 600 system can be found in references 4, 5, and 6.

EXPERIMENT DESCRIPTION

In order to test the concept of using a voice recognition device for Pseudo Pilot Station command inputs, an experiment similar to experiment number 1 described in reference 3 was conducted. (For data collection and analysis purposes only, the Threshold 600 system was linked to a Control Data Corporation CYBER 175 computer.) In reference 3, the language chosen for testing was that used by the nonradar or flight data controller in enroute centers. Two reasons for selecting this language were that it was one of the more complex languages in use and that the total repertoire of possible messages was larger than that of any of the other languages used in the control of aircraft. For these reasons and the similarity to the type of language to be used in MOTAS applications, and to provide a means for comparison with reference 3, this language was also chosen by LaRC to be used in the evaluation of the Threshold 600 system. It should be noted that in the experiment documented by reference 3, an earlier Threshold Technology system known as the VIP-100 system was used. The entire vocabulary which makes up this language is found in Table 1.

Training

The Threshold Technology 600 system must be prepared to recognize spoken words. This preparation is accomplished by training the system to recognize each individual's speech pronunciation patterns through the use of a built-in training routine. Each individual speaks ten utterances of each word or phrase in the vocabulary to allow optimization of the stored data for variations in speech pattern. During the training procedure, the Threshold

600 system prompts the individual for the word to be spoken and automatically sequences to the next word after the individual has spoken the word ten times. After the initial training for the evaluation, each individual spoke each word one time to determine if the Threshold 600 system would recognize the vocabulary. Any word misrecognized or rejected was retrained by the individual. This was done to help overcome word pattern optimization problems caused by nervousness, monotone speaking, low or high voice loudness level, and so forth; for example, problems which could be associated with confronting for the first time an unknown device (speaking to a computer) and unknown operating procedures. Once this training procedure was completed, the individuals were ready to begin the tests used for the evaluation of the system's performance.

Testing

A group of ten subjects was chosen to participate in the testing of the Threshold 600 system for recognition accuracy and word rejection frequency. This group was made up of six men and four women and their ages varied from the early twenties to the early fifties. The experiment was conducted in two phases: The first phase, which took place immediately after the initial training was completed, required that each subject randomly speak each of the tested words ten times during five different sessions spread over several weeks. In the second phase, each subject retrained any word which was misrecognized or rejected by the Threshold 600 system, and then was retested during two separate sessions to determine if any improvement in recognition and/or rejection rates had occurred.

The testing procedure used in this experiment was somewhat different from that used in reference 3. In reference 3, the 103-word vocabulary (Table 1) was divided into several subvocabularies depending on the ATC function of the word. Three of these subvocabularies (digits, messages, and fixes; Table 2) were each tested independently, that is, each word was tested for recognition against only those words in the subvocabulary. The LaRC experiment involved testing each word of these three subvocabularies for recognition against the entire 103-word vocabulary. This resulted in a more difficult experiment since it increased the probability for more words to be misrecognized for the spoken word. In addition, the subjects in reference 3 were retrained as the testing progressed instead of waiting until the end of an experiment phase as was the case with the LaRC experiment.

Initially, the environment chosen for the testing was very quiet. This was done in an effort to reproduce the conditions that would exist during MOTAS operations. Unfortunately, after the training was completed and the first phase of the experiment was begun, the environment became very noisy at times due to construction of a new aircraft simulator in an adjoining room. Intermittently, for the rest of the experiment, the subjects had to contend with constant background noise and periodic sharp noises caused by equipment being dropped, warning buzzers being tested, and so forth. While the background noise apparently did not affect the Threshold 600 system to any extent, the sharp noises had a definite impact resulting in misrecognition or rejection of spoken words, and spurious recognition or rejection when no word was being spoken. This obviously had an effect on the accuracy level of the

test results. In the MOTAS operational environment, this type of problem should not occur, and thus one would expect better results.

TEST RESULTS AND DISCUSSION

The test results and discussion will be broken down into four subject areas: (1) group recognition accuracy and rejection rate, (2) individual subject recognition accuracy and rejection rate, (3) individual word recognition accuracy and rejection rate, and (4) word pair confusion data.

Group Recognition Accuracy and Rejection Rate

As stated previously, a random sequence was generated for the words contained in Table 2, so that each word appeared ten times in the sequence. This led to a total of 480 words spoken during each test session. The 480 words were made up of 120 words from the digits subvocabulary, 150 words from the messages subvocabulary, and 210 words from the fixes subvocabulary. Figures 4 and 5 present the total group word recognition error and rejection rates, respectively. The figures are based on results obtained from ten subjects performing five tests each after the initial training and two tests each after retraining.

Figure 4 presents the recognition error data for the total 480 words and then separately for each subvocabulary. Maximum and minimum errors are shown for each phase of tests along with the average error for the group. Notice that in all cases, the retraining reduced both the average errors and the maximum errors thus decreasing the range of errors. The total error decreased from 3.67 percent to 1.96 percent. The worst results for the subvocabularies occurred with the digits group, which had a 5.67 percent error for initial

training and a 2.58 percent error after retraining. The results after the retraining were considered acceptable for the MOTAS Pseudo Pilot Station function, especially when one takes into account that further refinement may be obtained through additional retraining of problem words.

Figure 5 presents the rejection rate data for the total group. As with figure 4, the data are plotted for the total tested vocabulary and also for the three subvocabularies. Rejection rate data were taken using the following procedure: If a rejection occurred (the system could not match the word spoken with any word in the vocabulary), the word was respoken until a recognition, whether correct or incorrect, occurred. Each rejection for a word was counted, and then the total number of rejections for all words was compared to the total number of words for each vocabulary or subvocabulary. Thus, it was possible for more than one rejection to be counted as a single word was tested. Comparing figure 5 to figure 4, one can see that the rejection rate was much lower than the recognition error rate. The rejection rate was low initially, 0.68 percent, and was lowered only slightly to 0.49 percent after retraining. The digits subvocabulary, again, showed the worst rate after initial training. With retraining, it fell to the same region as the other subvocabularies.

Several factors were found from observation to contribute to the magnitude of the recognition error and rejection rates. These factors were: (1) environmental noise, (2) microphone position, (3) voice volume level, (4) voice peculiarities, (5) nervousness, and (6) colds.

Environmental noise.- The environmental noise was discussed previously, but it is worth pointing out again that sharp noises seemed to cause the

Threshold 600 system problems while constant background noise did not.

Microphone position.- The microphone position, as pointed out in references 3-6, proved to be a critical factor. If the microphone was placed too close to the mouth, it tended to pick up breathing noises from some of the subjects. When placed too far away or too far to the side of the mouth, it did not always pick up the spoken word or a good representation of the word, and it seemed to become more susceptible to extraneous noises.

Voice volume level.- The voice volume or loudness also appeared to be critical. Several of the subjects tended to have very soft voices which resulted in the Threshold 600 system not obtaining a good enough representation of the word spoken to recognize it. Indeed, once or twice a word was spoken where no input occurred at all. It was as if no word had been spoken.

Voice peculiarities and subject nervousness.- Voice peculiarities such as hissing sounds and lisping, and subject nervousness which manifested itself as soft voice levels, shaky voice, and frequent pausing and speaking of "eh" also caused recognition and rejection problems to varying degrees for several of the subjects.

Colds.- Finally, one of the subjects developed a cold during the first phase of testing which did affect the results as would be expected; however, the recognition and rejection rates were still in the acceptable region, thus no effort was made to retrain any words for that subject for the duration of the cold as was done for subjects in reference 3.

Individual Subject Recognition Accuracy and Rejection Rate

This section presents the results for recognition error and rejection rate for each individual subject for the total vocabulary and each of the three subvocabularies. In addition, group averages are given after the three worst subjects were removed (determined solely by the total vocabulary recognition error, since the rejection rates were much lower overall). This was done since there was a large difference between these three and the other subjects. Finally, the four best subjects (again determined by the same method) were chosen as if this would have been for a MOTAS study and the resulting group averages are presented.

Table 3 presents the total vocabulary recognition error for each subject based on their initial training. The individual subjects' averages varied from 0.96 to 7.46 percent with the group's overall average being 3.67 percent. The best subject (subject 9) had a range of scores from 0.21 to 1.25 percent for the five tests, while the worst subject (subject 5) had a range of 2.71 to 13.96 percent. When the three worst subjects (subjects 3, 5, and 7) were removed from the data base, the remaining seven subjects had an average recognition error of 2.25 percent. Finally, choosing the four best subjects (subjects 1, 2, 6, and 9) from the group of seven resulted in an average recognition error of 1.87 percent which was considered acceptable for the MOTAS application.

Table 4 presents the results of the digits subvocabulary recognition error for each subject. From an overall group point of view, this subvocabulary had the worst recognition error, 5.67 percent, and the average errors for individual subjects ranged from 1.00 to 11.83 percent. The best

subject (9) had recognition errors that ranged from 0.00 to 2.50 percent for an average of 1.00 percent; the worst subject (5) had errors that ranged from 2.50 to 21.67 percent for an average of 11.00 percent. Removing the three subjects (3, 5, 7) with the highest errors resulted in a group average of 3.19 percent. Finally, using only the four best subjects (1, 2, 6, 9) the group average error reduced to 2.33 percent.

Table 5 presents the results of the messages subvocabulary recognition error for each subject. The group average error for this subvocabulary was 3.33 percent, and the individual subjects' average errors varied from 0.53 to 9.07 percent. The best subject (9) had errors that ranged from 0.00 to 3.33 percent for an average of 1.33 percent; the worst subject (5) had errors that ranged from 3.33 to 20.00 percent for an average of 9.07 percent. Removing the three worst subjects (3, 5, 7) resulted in a group average error of 2.57 percent. The four best subjects (1, 2, 6, 9) yielded an average error of 2.37 percent.

Finally, Table 6 presents the results of the fixes subvocabulary recognition error for each subject. From an overall point of view, this subvocabulary had the best recognition error, 2.76 percent, and the individual subjects' average errors ranged from 0.57 to 8.76 percent. The best subject (9) had errors that ranged from 0.00 to 0.95 percent with an average of 0.67 percent; the worst subject (5) had errors that ranged from 2.38 to 6.19 percent for an average of 4.29 percent. Once again, removing the three worst subjects (3, 5, 7) resulted in a group average error of 1.48 percent. Grouping the four best subjects (1, 2, 6, 9) reduced the group average error to 1.24 percent.

Tables 7 through 10 present the results for the rejection rates for each individual subject based on their initial training. The average group rejection rate for the total vocabulary (Table 7) was 0.68 percent with the worst individual rate being 1.79 percent. All but two subjects (2, 5) registered a rejection rate of 0.75 percent or less. Thus, the rejection rate results were much better than the recognition error results and were considered acceptable for the MOTAS application. As with the recognition error results, the worst rejection rate occurred with the digits subvocabulary (Table 8); however, this was caused by subject 2 who had a very high rejection rate as compared to the other subjects. When subject 2 was removed from the data base, the group digits average rejection rate fell in line with the other subvocabularies. For the other two subvocabularies (Tables 9 and 10), subject 5 was found to have the worst results.

Table 11 presents the total vocabulary recognition error for each subject after retraining. By comparing this table with Table 3, one can see the improvement which occurred after retraining. The group average recognition error dropped from 3.67 to 1.96 percent. Notice, however, that for two subjects (8, 9), the recognition error increased. In one case (9), there was a slight increase (0.96 to 1.35 percent) which was attributed to a recognition problem with a word that had not occurred in the initial testing and thus had not been retrained. For the second subject (8), the recognition error more than doubled. The majority of this increase was caused by two words; one which more than tripled in recognition error, and the second which almost doubled, thus indicating that the retraining of these two words was unsuccessful. For the four best subjects (1, 2, 6, 9), the group average

recognition error after retraining was 1.07 percent, a substantial reduction. In addition to these four, a fifth subject (4) would have qualified after retraining under the original definition for best four and was in fact the best performing of the subjects after retraining with a recognition error of 0.31 percent. Substituting this subject for the worst performer of the original four subjects further reduces the four subject group recognition error to 0.81 percent. Tables 12 through 14 present the recognition error data for the three subvocabularies for each subject after retraining. Comparing to Tables 4 through 6, one sees that the recognition error for the group reduced from 5.67 to 2.58 percent for digits, from 3.33 to 1.70 percent for messages, and from 2.76 to 1.79 percent for fixes.

Tables 15 through 18 present the rejection rate data for the subjects after retraining. As before, the rejection rate was lower than the recognition error. Some improvement did occur (0.68 to 0.49 percent for the total vocabulary); however, because the rejection rate was so low, a single rejection could cause the results to appear to fluctuate. For example, one rejection in one test equalled a 0.21 percent rejection rate for that test.

Individual Word Recognition Accuracy and Rejection Rate

This section presents the recognition error and rejection rate results for each of the individual words tested (Table 2) for the entire group of subjects. The data are presented for subjects tested after the initial training and after retraining. When comparing this data to the results of reference 3, the reader is reminded (see previous discussion of experiment differences) that the experiment in reference 3 was more restricted in vocabulary size which contributed to the increased performance of the voice

recognition system and that retraining occurred as was required during testing and not as a separate test.

Table 19 presents the results for the digits subvocabulary. For all words, there was an improvement in recognition error after the retraining was completed. A very large improvement occurred for the words FIVE (15.40 to 3.50 percent) and SIX (10.60 to 3.50 percent). The words ONE and NINER showed only slight improvement in recognition error after retraining. At 6.00 percent and 8.00 percent, respectively, these words were the only two of the entire subvocabulary with recognition errors that were over 3.50 percent. For rejection rate, three words increased slightly while all of the other words improved.

Table 20 presents the results for the messages subvocabulary. Eleven of the fifteen words showed recognition error improvement after retraining. One additional word showed only a slight increase in recognition error (0.40 to 0.50 percent). The words AMEND (11.80 to 3.50 percent), PRINTSTRIP (7.80 to 0.50 percent), and REPORTALTITUDE (5.20 to 0.50 percent) showed the most improvement after retraining while the words CORRECTION (0.60 to 2.50 percent), HANDOFF (3.80 to 5.00 percent), and TRANSMIT (5.80 to 7.00 percent) increased in recognition error. For rejection rate, ten words showed improvement, but five words showed worse rates of rejection. Notice for the word AMEND, there was an increase in rejection rate (1.60 to 6.50 percent), while at the same time a decrease in recognition error (11.80 to 3.50 percent). Thus, some of the recognition errors appeared to become rejections after retraining.

Table 21 presents the results for the fixes subvocabulary. Sixteen of the words showed recognition error improvement after retraining. TOBYHANNA (4.20 to 0.50 percent), STILLWATER (6.20 to 2.00 percent), and BENTON (18.20 to 7.50 percent) showed the largest improvements, while the word FREELAND (3.80 to 9.50 percent) showed the greatest increase in recognition error. All but three words showed a decrease in rejection rate. As with the recognition error, the word FREELAND showed the greatest rejection rate increase (1.60 to 6.50 percent) after retraining.

Word Pair Confusion

This section presents data on the confusion between word pairs, that is, the words which were misrecognized for the spoken word. Tables 22 through 24 present the results on the number of different words misrecognized for a given spoken word after initial training and after retraining. Tables 25 through 30 present the individual spoken words along with the corresponding misrecognized words and the percentage of occurrence. For all three subvocabularies, the number of words misrecognized for a spoken word after retraining either decreased or in a few cases (5 words) remained the same; the lone exception was the word SELINGSGROVE which increased from one to two misrecognized words. Looking at Tables 25 through 30, one can see that a large number of the misrecognized words did not belong to the tested vocabulary (Table 2), but did belong to the total vocabulary (Table 1) that was programmed in the Threshold 600 system. For example (see Tables 22 and 25), 34 of the 62 misrecognized words were not part of the tested vocabulary. It is conceivable that the number of misrecognized words would decrease (no new additional

misrecognized words) if the total programmed vocabulary was reduced to only the tested vocabulary; however, the setup as used served the purpose of evaluating a worst case situation where the programmed vocabulary approached the maximum number of words allowable. If nontested words are removed from Tables 22 through 24, the totals would change as follows:

Table 22 - 62 would change to 28 for initial training; 28 would change to 10 for retraining

Table 23 - 77 would change to 35 for initial training; 21 would change to 8 for retraining

Table 24 - 105 would change to 58 for initial training; 39 would change to 22 for retraining.

CONCLUDING REMARKS

This paper has described the evaluation of voice recognition technology and specifically, the Threshold 600 Voice Recognition System for use in the MOTAS Pseudo Pilot Station function where the Threshold 600 system would act as an aircraft control input device.

The experiment results showed the recognition error after initial training to be 3.67 percent for ten subjects when testing a 48-word vocabulary against a 103-word programmed vocabulary. After the ten subjects had retrained words which had been misrecognized or rejected, the recognition error decreased to 1.96 percent. The rejection rates for both cases were found to be less than 0.70 percent. The recognition error was reduced even further when the four best subjects were chosen as if they were to operate the four MOTAS Pseudo Pilot Stations. It is conceivable, based on other similar

studies, that the recognition error could also have been reduced if only the 48 test words had been programmed; however, one of the parameters of the experiment was to use as large a programmed vocabulary as practical for the testing.

There are several operational characteristics of MOTAS which would appear to provide additional means for reducing the recognition error: (1) a smaller operational vocabulary which at this time is defined as containing 44 words in the total vocabulary, (2) the vocabulary does not contain as many word pairs which appear to sound alike and thus would be susceptible to misrecognition; and with those word pairs that do occur, the flexibility exists to change one of the words and still achieve the desired results, (3) multiple retraining to continually reduce the number of problem words that an operator encounters, and (4) the MOTAS Pseudo Pilot Stations will be setup so that the operator can preview and edit the output from the voice recognition device before the input is made to the aircraft model.

Thus, based on the above reasons and the acceptable results obtained from the described experiment, the decision was made to use voice recognition technology and specifically, the Threshold 600 Voice Recognition System to perform the MOTAS Pseudo Pilot Station function.

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TABLE 1.- PROGRAMMED VOCABULARY.

ZERO
ONE
TWO
THREE
FOUR
FIVE
SIX
SEVEN
EIGHT
NINER
BACKSPACE
GO
AMEND
CANCEL
CORRECTION
DEPARTURE
DISCRETECODE
READOUT
ACCEPTHANDOFF
HANDOFF
DROPTRACK
PRINTSTRIP
HOLD
RELEASE
REPORTALTITUDE
WEATHER
TRANSMIT
TYPE
QUALIFIER
BEACONCODE
SPEED
FIX
TIME
ALTITUDE
IDENT
WILLIAMSPORT
SELINGSGROVE
MILTON
HAZELTON
WILKESBARRE
EASTTEXAS
LAKEHENRY
TOBYHANNA
ALLENTOWN
STILLWATER
BENTON
SWEETVALLEY
LOPEZ
SNYDERS
SLATINGTON
WHITEHAVEN
RESORT
PENNWELL
HUGUENOT
SOLBERG
FREELAND
BOEING
DOUGLAS
LOCKHEED
CONVAIR
VICKERS
NORD
BRITISH
GENERAL
MILITARY
DEHAVILLAND
ALPHA
BRAVO
CHARLIE
DELTA
ECHO
FOXTROT
GOLF
HOTEL
INDIA
JULIET
KILO
LIMA
MIKE
NOVEMBER
OSCAR
PAPA
QUEBEC
ROMEO
SIERRA
TANGO
UNIFORM
VICTOR
WHISKEY
XRAY
YANKEE
ZULU
DISCRETE
DISCRETEDME
DME
NONDISCRETE
NONDISCRETEDME
TRANSPONDER
TRANSPONDERDME
TACAN
TACAN64
TACANDISCRETE
ERASE

TABLE 2.- EXPERIMENT VOCABULARY.

a-DIGITS	b-MESSAGES	c-FIXES
ZERO	AMEND	WILLIAMSPORT
ONE	CANCEL	SELINGSGROVE
TWO	CORRECTION	MILTON
THREE	DEPARTURE	HAZELTON
FOUR	DISCRETECODE	WILKESBARRE
FIVE	READOUT	EASTTEXAS
SIX	ACCEPTHANDOFF	LAKEHENRY
SEVEN	HANDOFF	TOBYHANNA
EIGHT	DROPTRACK	ALLENTOWN
NINER	PRINTSTRIP	STILLWATER
BACKSPACE	HOLD	BENTON
ERASE	RELEASE	SWEETVALLEY
	REPORTALTITUDE	LOPEZ
	WEATHER	SNYDERS
	TRANSMIT	SLATINGTON
		WHITEHAVEN
		RESORT
		PENNWELL
		HUGUENOT
		SOLBERG
		FREELAND

TABLE 3. - SUBJECT TOTAL TEST VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	2.50	1.67	1.88	2.50	1.46	2.00
2	1.46	2.71	1.67	2.92	2.29	2.21
3	6.88	5.83	6.67	9.79	7.71	7.38
4	2.08	2.08	1.67	2.50	4.17	2.50
5	2.71	9.79	13.96	6.46	4.38	7.46
6	3.96	2.71	1.46	1.04	2.29	2.29
7	7.92	8.96	5.63	5.42	2.50	6.08
8	1.04	1.25	3.54	2.71	3.75	2.46
9	0.21	1.04	1.25	1.04	1.25	0.96
10	1.67	2.50	2.92	4.58	5.00	3.33
TOTAL						3.67

TABLE 4. - SUBJECT DIGITS VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	1.67	0.83	0.83	0.83	0.83	1.00
2	4.17	5.83	4.17	9.17	8.33	6.33
3	10.83	9.17	9.17	15.83	12.50	11.50
4	4.17	0.83	3.33	0.83	5.00	2.83
5	2.50	19.17	21.67	5.83	5.83	11.00
6	2.50	0.83	0.00	0.00	1.67	1.00
7	15.83	24.17	8.33	3.33	7.50	11.83
8	3.33	0.83	6.67	6.67	5.00	4.50
9	0.00	1.67	2.50	0.00	0.83	1.00
10	1.67	1.67	5.00	5.83	14.17	5.67
TOTAL						5.67

TABLE 5. - SUBJECT MESSAGES VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	3.33	3.33	1.33	6.00	1.33	3.07
2	0.67	0.67	0.00	1.33	0.00	0.53
3	2.67	0.00	3.33	4.67	0.00	2.13
4	1.33	0.67	1.33	2.67	3.33	1.87
5	3.33	10.67	20.00	7.33	4.00	9.07
6	6.67	4.67	4.00	2.67	4.67	4.53
7	4.00	2.67	3.33	10.67	0.00	4.13
8	0.00	2.67	1.33	1.33	1.33	1.33
9	0.00	0.67	0.67	3.33	2.00	1.33
10	4.00	6.67	4.67	8.67	2.67	5.33
TOTAL						3.33

TABLE 6. - SUBJECT FIXES VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	2.38	0.95	2.86	0.95	1.90	1.81
2	0.48	2.38	1.43	0.48	0.48	1.05
3	7.62	8.10	7.62	10.00	10.48	8.76
4	1.43	3.81	0.95	3.33	4.29	2.76
5	2.38	3.81	5.24	6.19	3.81	4.29
6	2.86	2.38	0.48	0.48	0.95	1.43
7	6.19	4.76	5.71	2.86	1.43	4.19
8	0.48	0.48	3.33	1.43	4.76	2.10
9	0.48	0.95	0.95	0.00	0.95	0.67
10	0.00	0.00	0.48	0.95	1.43	0.57
TOTAL						2.76

TABLE 7. - SUBJECT TOTAL TEST VOCABULARY PERCENT REJECT PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	0.42	0.00	0.42	0.42	0.21	0.29
2	4.17	0.83	1.67	0.63	1.25	1.71
3	1.46	0.21	0.00	0.21	1.46	0.67
4	0.00	0.00	0.00	0.21	0.00	0.04
5	2.71	2.29	1.25	0.63	2.08	1.79
6	0.63	0.21	0.83	1.04	0.00	0.54
7	0.00	0.42	0.21	0.21	0.00	0.17
8	0.42	0.42	0.42	0.63	0.42	0.46
9	0.83	0.00	0.42	0.42	0.21	0.38
10	0.63	0.00	0.00	1.88	1.25	0.75
TOTAL						0.68

TABLE 8. - SUBJECT DIGITS VOCABULARY PERCENT REJECT PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	0.00	0.00	0.00	0.83	0.00	0.17
2	14.17	3.33	4.17	1.67	5.00	5.67
3	0.00	0.00	0.00	0.83	3.33	0.83
4	0.00	0.00	0.00	0.00	0.00	0.00
5	1.67	0.00	0.83	0.83	0.00	0.67
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	1.67	0.83	0.00	0.00	0.50
8	0.83	0.83	0.83	0.00	0.00	0.50
9	0.00	0.00	1.67	0.00	0.00	0.33
10	0.83	0.00	0.00	3.33	2.50	1.33
TOTAL						1.00

TABLE 9. - SUBJECT MESSAGES VOCABULARY PERCENT REJECT PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	0.00	0.00	1.33	0.00	0.67	0.40
2	0.00	0.00	0.67	0.67	0.00	0.27
3	0.00	0.00	0.00	0.00	0.67	0.13
4	0.00	0.00	0.00	0.00	0.00	0.00
5	4.67	1.33	0.67	0.00	1.33	1.60
6	1.33	0.00	0.67	3.33	0.00	1.07
7	0.00	0.00	0.00	0.67	0.00	0.13
8	0.67	0.00	0.00	0.00	0.00	0.13
9	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	2.67	0.00	0.53
TOTAL						0.43

TABLE 10. - SUBJECT FIXES VOCABULARY PERCENT REJECT PERFORMANCE (INITIAL TRAINING).

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TOTAL
1	0.95	0.00	0.00	0.48	0.00	0.29
2	1.43	0.00	0.95	0.00	0.00	0.48
3	3.33	0.48	0.00	0.00	0.95	0.95
4	0.00	0.00	0.00	0.48	0.00	0.10
5	1.90	4.29	1.90	0.95	3.81	2.57
6	0.48	0.48	1.43	0.00	0.00	0.48
7	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.48	0.48	1.43	0.95	0.67
9	1.90	0.00	0.00	0.95	0.48	0.67
10	0.95	0.00	0.00	0.48	1.43	0.57
TOTAL						0.68

TABLE 11. - SUBJECT TOTAL TEST VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.83	1.67	1.25
2	0.63	0.21	0.42
3	2.29	1.04	1.67
4	0.42	0.21	0.31
5	2.29	5.21	3.75
6	1.04	1.46	1.25
7	2.29	1.88	2.08
8	5.00	5.42	5.21
9	2.08	0.63	1.35
10	2.08	2.50	2.29
TOTAL			1.96

TABLE 12. - SUBJECT DIGITS VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	1.67	1.67	1.67
2	0.00	0.83	0.42
3	6.67	1.67	4.17
4	1.67	0.00	0.83
5	1.67	6.67	4.17
6	0.00	0.83	0.42
7	4.17	1.67	2.92
8	5.83	7.50	6.67
9	1.67	0.83	1.25
10	0.83	5.83	3.33
TOTAL			2.58

TABLE 13. - SUBJECT MESSAGES VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.00	1.33	0.67
2	0.67	0.00	0.33
3	0.67	1.33	1.00
4	0.00	0.00	0.00
5	1.33	8.00	4.67
6	2.67	3.33	3.00
7	1.33	0.00	0.67
8	0.67	2.67	1.67
9	4.67	0.67	2.67
10	2.67	2.00	2.33
TOTAL			1.70

TABLE 14. - SUBJECT FIXES VOCABULARY PERCENT RECOGNITION ERROR PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.95	1.90	1.43
2	0.95	0.00	0.48
3	0.95	0.48	0.71
4	0.00	0.48	0.24
5	3.33	2.38	2.86
6	0.48	0.48	0.48
7	1.90	3.33	2.62
8	7.62	6.19	6.90
9	0.48	0.48	0.48
10	2.38	0.95	1.67
TOTAL			1.79

TABLE 15. - SUBJECT TOTAL TEST VOCABULARY PERCENT REJECT PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.00	0.21	0.10
2	0.21	0.63	0.42
3	0.21	0.00	0.10
4	0.21	0.00	0.10
5	2.71	0.00	1.35
6	0.63	0.21	0.42
7	0.00	0.00	0.00
8	2.50	1.46	1.98
9	0.00	0.42	0.21
10	0.21	0.21	0.21
TOTAL			0.49

TABLE 16. - SUBJECT DIGITS VOCABULARY PERCENT REJECT PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.00	0.00	0.00
2	0.00	2.50	1.25
3	0.83	0.00	0.42
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.83	0.00	0.42
7	0.00	0.00	0.00
8	2.50	0.00	1.25
9	0.00	0.00	0.00
10	0.83	0.83	0.83
TOTAL			0.42

TABLE 17. - SUBJECT MESSAGES VOCABULARY PERCENT REJECT PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.00	0.00	0.00
2	0.67	0.00	0.33
3	0.00	0.00	0.00
4	0.67	0.00	0.33
5	8.67	0.00	4.33
6	1.33	0.00	0.67
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	1.33	0.67
10	0.00	0.00	0.00
TOTAL			0.63

TABLE 18. - SUBJECT FIXES VOCABULARY PERCENT REJECT PERFORMANCE (RETRAINED).

SUBJECT	TEST 1	TEST 2	TOTAL
1	0.00	0.48	0.24
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.48	0.24
7	0.00	0.00	0.00
8	4.29	3.33	3.81
9	0.00	0.00	0.00
10	0.00	0.00	0.00
TOTAL			0.43

TABLE 19. - DIGITS TEST RESULTS.

WORD	INITIAL PERCENT ERROR	RETRAINED PERCENT ERROR	INITIAL PERCENT REJECT	RETRAINED PERCENT REJECT
ZERO	2.00	1.50	0.00	0.00
ONE	8.20	6.00	0.20	0.00
TWO	4.20	1.50	0.60	1.00
THREE	4.80	2.00	0.00	0.00
FOUR	2.40	1.00	2.80	0.50
FIVE	15.40	3.50	4.40	0.50
SIX	10.60	3.50	1.80	0.00
SEVEN	1.80	1.00	0.60	0.50
EIGHT	6.40	3.00	1.40	2.00
NINER	9.40	8.00	0.00	0.00
BACKSPACE	0.80	0.00	0.20	0.50
ERASE	2.00	0.00	0.00	0.00
TOTAL	5.67	2.58	1.00	0.42

TABLE 20. - MESSAGES TEST RESULTS.

WORD	INITIAL PERCENT ERROR	RETRAINED PERCENT ERROR	INITIAL PERCENT REJECT	RETRAINED PERCENT REJECT
AMEND	11.80	3.50	1.60	6.50
CANCEL	0.80	0.50	0.20	0.00
CORRECTION	0.60	2.50	0.60	0.00
DEPARTURE	3.60	1.00	0.80	0.00
DISCRETECODE	1.20	0.00	0.00	0.50
READOUT	0.20	0.00	0.00	0.00
ACCEPTHANDOFF	0.00	0.00	0.80	0.00
HANDOFF	3.80	5.00	0.40	0.50
DROPTRACK	1.40	0.50	0.20	0.00
PRINTSTRIP	7.80	0.50	0.40	1.00
HOLD	0.60	0.00	0.00	0.00
RELEASE	6.80	4.00	0.20	0.00
REPORTALTITUDE	5.20	0.50	0.80	0.00
WEATHER	0.40	0.50	0.20	1.00
TRANSMIT	5.80	7.00	0.40	0.00
TOTAL	3.33	1.70	0.43	0.63

TABLE 21. - FIXES TEST RESULTS.

WORD	INITIAL PERCENT ERROR	RETRAINED PERCENT ERROR	INITIAL PERCENT REJECT	RETRAINED PERCENT REJECT
WILLIAMSPORT	0.60	0.50	0.20	0.00
SELINGSGROVE	0.20	1.00	0.00	0.00
MILTON	5.80	7.50	2.80	1.00
HAZELTON	0.80	0.50	1.20	0.00
WILKESBARRE	0.00	0.00	0.60	0.00
EASTTEXAS	0.60	0.00	0.00	0.00
LAKEHENRY	0.20	0.50	0.20	0.00
TOBYHANNA	4.20	0.50	1.00	0.00
ALLENTOWN	1.80	0.00	2.20	0.00
STILLWATER	6.20	2.00	0.20	0.50
BENTON	18.20	7.50	2.60	0.50
SWEETVALLEY	1.20	0.00	0.00	0.00
LOPEZ	1.60	0.00	0.20	0.00
SNYDERS	1.60	1.50	0.00	0.50
SLATINGTON	2.60	0.50	0.00	0.00
WHITEHAVEN	2.80	0.50	0.20	0.00
RESORT	0.60	0.00	0.20	0.00
PENNWELL	0.40	0.00	0.00	0.00
HUGUENOT	3.80	4.50	0.40	0.00
SOLBERG	1.00	1.00	0.40	0.00
FREELAND	3.80	9.50	1.60	6.50
TOTAL	2.76	1.79	0.68	0.43

TABLE 22. - WORD CONFUSION SUMMARY, DIGITS.

WORD	NUMBER OF WORDS CONFUSED	
	INITIAL	RETRAINED
ZERO	5	1
ONE	3	3
TWO	6	3
THREE	7	2
FOUR	3	1
FIVE	9	3
SIX	2	1
SEVEN	5	2
EIGHT	5	5
NINER	13	7
BACKSPACE	2	0
ERASE	2	0
TOTAL	62	28

TABLE 23. - WORD CONFUSION SUMMARY, MESSAGES.

WORD	NUMBER OF WORDS CONFUSED	
	INITIAL	RETRAINED
AMEND	14	3
CANCEL	4	1
CORRECTION	3	3
DEPARTURE	10	2
DISCRETECODE	5	0
READOUT	1	0
ACCEPTHANDOFF	0	0
HANDOFF	10	4
DROPTRACK	5	1
PRINTSTRIP	6	1
HOLD	2	0
RELEASE	3	3
REPORTALTITUDE	5	1
WEATHER	2	1
TRANSMIT	7	1
TOTAL	77	21

TABLE 24. - WORD CONFUSION SUMMARY, FIXES.

WORD	NUMBER OF WORDS CONFUSED	
	INITIAL	RETRAINED
WILLIAMSPORT	2	1
SELINGSGROVE	1	2
MILTON	8	5
HAZELTON	3	1
WILKESBARRE	0	0
EASTTEXAS	3	0
LAKEHENRY	1	1
TOBYHANNA	5	1
ALLENTOWN	3	0
STILLWATER	4	3
BENTON	22	7
SWEETVALLEY	5	0
LOPEZ	4	0
SNYDERS	6	2
SLATINGTON	6	1
WHITEHAVEN	5	1
RESORT	2	0
PENNWELL	2	0
HUGUENOT	10	4
SOLBERG	3	2
FREELAND	10	8
TOTAL	105	39

TABLE 25. - WORD CONFUSION, DIGITS (INITIAL TRAINING).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
ZERO	KILO(40.0), SIERRA(30.0), DISCRETECODE(10.0), SEVEN(10.0), SWEETVALLEY(10.0)
ONE	NORD(63.4), BOEING(31.7), MIKE(4.9)
TWO	SPEED(57.1), GENERAL(14.3), HAZELTON(14.3), DME(4.8), THREE(4.8), UNIFORM(4.8)
THREE	DISCRETE(33.3), SPEED(33.3), SLATINGTON(12.5), SNYDERS(8.3), BRITISH(4.2), CORRECTION(4.2), TWO(4.2)
FOUR	SOLBERG(50.0), NORD(25.0), STILLWATER(25.0)
FIVE	TYPE(44.2), TIME(22.1), SOLBERG(9.1), CHARLIE(6.5), MIKE(6.5), NINER(6.5), PAPA(2.6), LIMA(1.3), STILLWATER(1.3)
SIX	FIX(98.1), SLATINGTON(1.9)
SEVEN	BENTON(55.6), DME(11.1), SWEETVALLEY(11.1), TYPE(11.1), WHISKEY(11.1)
EIGHT	HAZELTON(56.3), SPEED(18.8), VICTOR(12.5), FIX(9.4), YANKEE(3.1)
NINER	MILITARY(40.4), WEATHER(14.9), TIME(10.6), FREELAND(6.5), MIKE(6.5), SNYDERS(4.3), VICTOR(4.3), ALTITUDE(2.1), DISCRETE(2.1), DEPARTURE(2.1), SEVEN(2.1), SLATINGTON(2.1), TOBYHANNA(2.1)
BACKSPACE	XRAY(75.0), SLATINGTON(25.0)
ERASE	RELEASE(80.0), THREE(20.0)

TABLE 26. - WORD CONFUSION, MESSAGES (INITIAL TRAINING).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
AMEND	IDENT(64.4), TRANSMIT(8.5), DISCRETEDME(3.4), FREELAND(3.4), TOBYHANNA(3.4), VICKERS(3.4), ALTITUDE(1.7), EIGHT(1.7), HOLD(1.7), INDIA(1.7), LOPEZ(1.7), MILITARY(1.7), THREE(1.7), WHITEHAVEN(1.7)
CANCEL	EIGHT(25.0), TACAN64(25.0), VICKERS(25.0), WILLIAMSPORT(25.0)
CORRECTION	BRITISH(33.3), DEPARTURE(33.3), ERASE(33.3)
DEPARTURE	WHITEHAVEN(27.8), ALTITUDE(16.7), CONVAIR(11.1), MIKE(11.1), CORRECTION(5.6), NINER(5.6), NONDISCRETE(5.6), QUEBEC(5.6), TRANSPONDERDME(5.6), WEATHER(5.6)
DISCRETECODE	SWEETVALLEY(33.3), BEACONCODE(16.7), DISCRETE(16.7), FREELAND(16.7), SPEED(16.7)
READOUT	HUGUENOT(100.0)
ACCEPTHANDOFF	NO WORDS CONFUSED
HANDOFF	PENNWELL(26.3), HUGUENOT(15.8), NINER(15.8), KILO(10.5), ALLENTOWN(5.3), GOLF(5.3), LAKEHENRY(5.3), SWEETVALLEY(5.3), TANGO(5.3), TRANSPONDER(5.3)
DROPTRACK	FIVE(28.6), FOXTROT(28.6), MILITARY(14.3), NINER(14.3), QUEBEC(14.3)
PRINTSTRIP	VICTOR(82.1), IDENT(5.1), TRANSMIT(5.1), DISCRETE(2.6), NONDISCRETE(2.6), XRAY(2.6)
HOLD	GOLF(66.7), BRAVO(33.3)
RELEASE	BRITISH(76.5), ERASE(20.6), FIX(2.9)
REPORTALTITUDE	DEPARTURE(80.8), LOCKHEED(7.7), MILITARY(3.9), PENNWELL(3.9), UNIFORM(3.9)
WEATHER	NINER(50.0), WHISKEY(50.0)
TRANSMIT	PRINTSTRIP(58.6), VICTOR(20.7), BENTON(6.9), CANCEL(3.5), FREELAND(3.5), MILITARY(3.5), TACAN(3.5)

TABLE 27. - WORD CONFUSION, FIXES (INITIAL TRAINING).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
WILLIAMSPORT	RESORT(66.7), FREELAND(33.3)
SELINGSGROVE	SLATINGTON(100.0)
MILTON	MILITARY(34.5), DELTA(24.1), DEHAVILLAND(13.8), GO(10.3), NONDISCRETE(6.9), DEPARTURE(3.5), IDENT(3.5), NORD(3.5)
HAZELTON	EIGHT(50.0), DISCRETE(25.0), REPORTALTITUDE(25.0)
WILKESBARRE	NO WORDS CONFUSED
EASTTEXAS	BACKSPACE(33.3), RELEASE(33.3), XRAY(33.3)
LAKEHENRY	SEVEN(100.0)
TOBYHANNA	FREELAND(52.4), SWEETVALLEY(23.8), AMEND(14.3), MILITARY(4.8), NOVEMBER(4.8)
ALLENTOWN	ALTITUDE(66.7), IDENT(22.2), NINER(11.1)
STILLWATER	SOLBERG(87.1), NORD(6.5), DELTA(3.2), DISCRETECODE(3.2)
BENTON	NONDISCRETE(30.8), FIX(11.0), YANKEE(8.8), EIGHT(6.6), HAZELTON(5.5), MILTON(5.5), TWO(5.5), TACANDISCRETE(3.3), TRANSPONDER(3.3), AMEND(2.2), SNYDERS(2.2), TACAN(2.2), VICKERS(2.2), VICTOR(2.2), BRITISH(1.1), CORRECTION(1.1), DISCRETE(1.1), DME(1.1), ERASE(1.1), FREELAND(1.1), REPORTALTITUDE(1.1), SIX(1.1)
SWEETVALLEY	DISCRETE(33.3), FREELAND(16.7), HUGUENOT(16.7), READOUT(16.7), SEVEN(16.7)
LOPEZ	BACKSPACE(37.5), MILITARY(37.5), HOLD(12.5), HOTEL(12.5)
SNYDERS	IDENT(25.0), TYPE(25.0), BACKSPACE(12.5), FREELAND(12.5), NINER(12.5), SWEETVALLEY(12.5)
SLATINGTON	SNYDERS(23.1), THREE(23.1), DISCRETE(15.4), SIX(15.4), SPEED(15.4), DME(7.7)
WHITEHAVEN	LAKEHENRY(50.0), IDENT(21.4), BACKSPACE(14.3), LOCKHEED(7.1), TYPE(7.1)
RESORT	WILLIAMSPORT(66.7), THREE(33.3)
PENNWELL	FREELAND(50.0), HANDOFF(50.0)
HUGUENOT	READOUT(31.6), FREELAND(10.5), HANDOFF(10.5), SIERRA(10.5), SWEETVALLEY(10.5), BEACONCODE(5.3), BENTON(5.3), LIMA(5.3), SIX(5.3), ZULU(5.3)
SOLBERG	NORD(40.0), STILLWATER(40.0), CHARLIE(20.0)
FREELAND	BENTON(26.3), THREE(15.8), AMEND(10.5), LIMA(10.5), ZULU(10.5), DISCRETEDME(5.3), KILO(5.3), SLATINGTON(5.3), WILLIAMSPORT(5.3), ZERO(5.3)

TABLE 28. - WORD CONFUSION, DIGITS (RETRAINED).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
ZERO	SIERRA(100.0)
ONE	BOEING(83.3), THREE(8.3), NORD(8.3)
TWO	FREELAND(33.3), LIMA(33.3), SPEED(33.3)
THREE	SPEED(75.0), DISCRETE(25.0)
FOUR	HOLD(100.0)
FIVE	TIME(42.9), TYPE(42.9), MIKE(14.3)
SIX	FIX(100.0)
SEVEN	FREELAND(50.0), SLATINGTON(50.0)
EIGHT	THREE(33.3), TACANDISCRETE(16.7), TYPE(16.7), VICTOR(16.7), YANKEE(16.7)
NINER	WEATHER(37.5), SNYDERS(25.0), VICTOR(12.5), CONVAIR(6.3), FREELAND(6.3), MILITARY(6.3), TWO(6.3)
BACKSPACE	NO WORDS CONFUSED
ERASE	NO WORDS CONFUSED

TABLE 29. - WORD CONFUSION, MESSAGES (RETRAINED).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
AMEND	IDENT(71.4), MILITARY(14.3), TRANSMIT(14.3)
CANCEL	UNIFORM(100.0)
CORRECTION	QUEBEC(60.0), BRITISH(20.0), WHITEHAVEN(20.0)
DEPARTURE	CONVAIR(50.0), NORD(50.0)
DISCRETECODE	NO WORDS CONFUSED
READOUT	NO WORDS CONFUSED
ACCEPTHANDOFF	NO WORDS CONFUSED
HANDOFF	TANGO(40.0), HUGUENOT(30.0), CANCEL(20.0), GO(10.0)
DROPTRACK	MILITARY(100.0)
PRINTSTRIP	TRANSMIT(100.0)
HOLD	NO WORDS CONFUSED
RELEASE	ERASE(75.0), BRITISH(12.5), FIX(12.5)
REPORTALTITUDE	DEPARTURE(100.0)
WEATHER	BRAVO(100.0)
TRANSMIT	PRINTSTRIP(100.0)

TABLE 30. - WORD CONFUSION, FIXES (RETRAINED).

WORD	WORD CONFUSED (PERCENT OF TOTAL CONFUSION)
WILLIAMSPORT	RESORT(100.0)
SELINGSGROVE	DELTA(50.0), MILITARY(50.0)
MILTON	DELTA(73.3), BENTON(6.7), DME(6.7), GO(6.7), NONDISCRETE(6.7)
HAZELTON	EIGHT(100.0)
WILKESBARRE	NO WORDS CONFUSED
EASTTEXAS	NO WORDS CONFUSED
LAKEHENRY	WHITEHAVEN(100.0)
TOBYHANNA	AMEND(100.0)
ALLENTOWN	NO WORDS CONFUSED
STILLWATER	FOUR(50.0), NORD(25.0), SOLBERG(25.0)
BENTON	HAZELTON(26.7), TWO(26.7), DISCRETE(20.0), FREELAND(6.7), TACAN(6.7), TRANSPONDERDME(6.7), WHISKEY(6.7)
SWEETVALLEY	NO WORDS CONFUSED
LOPEZ	NO WORDS CONFUSED
SNYDERS	IDENT(66.7), VICKERS(33.3)
SLATINGTON	SPEED(100.0)
WHITEHAVEN	LAKEHENRY(100.0)
RESORT	NO WORDS CONFUSED
PENNWELL	NO WORDS CONFUSED
HUGUENOT	SWEETVALLEY(44.4), ZERO(33.3), HAZELTON(11.1), SIERRA(11.1)
SOLBERG	FOUR(50.0), FREELAND(50.0)
FREELAND	THREE(36.8), SLATINGTON(15.8), TACAN(15.8), TOBYHANNA(10.5), DISCRETECODE(5.3), LIMA(5.3), REPORTALTITUDE(5.3), SWEETVALLEY(5.3)

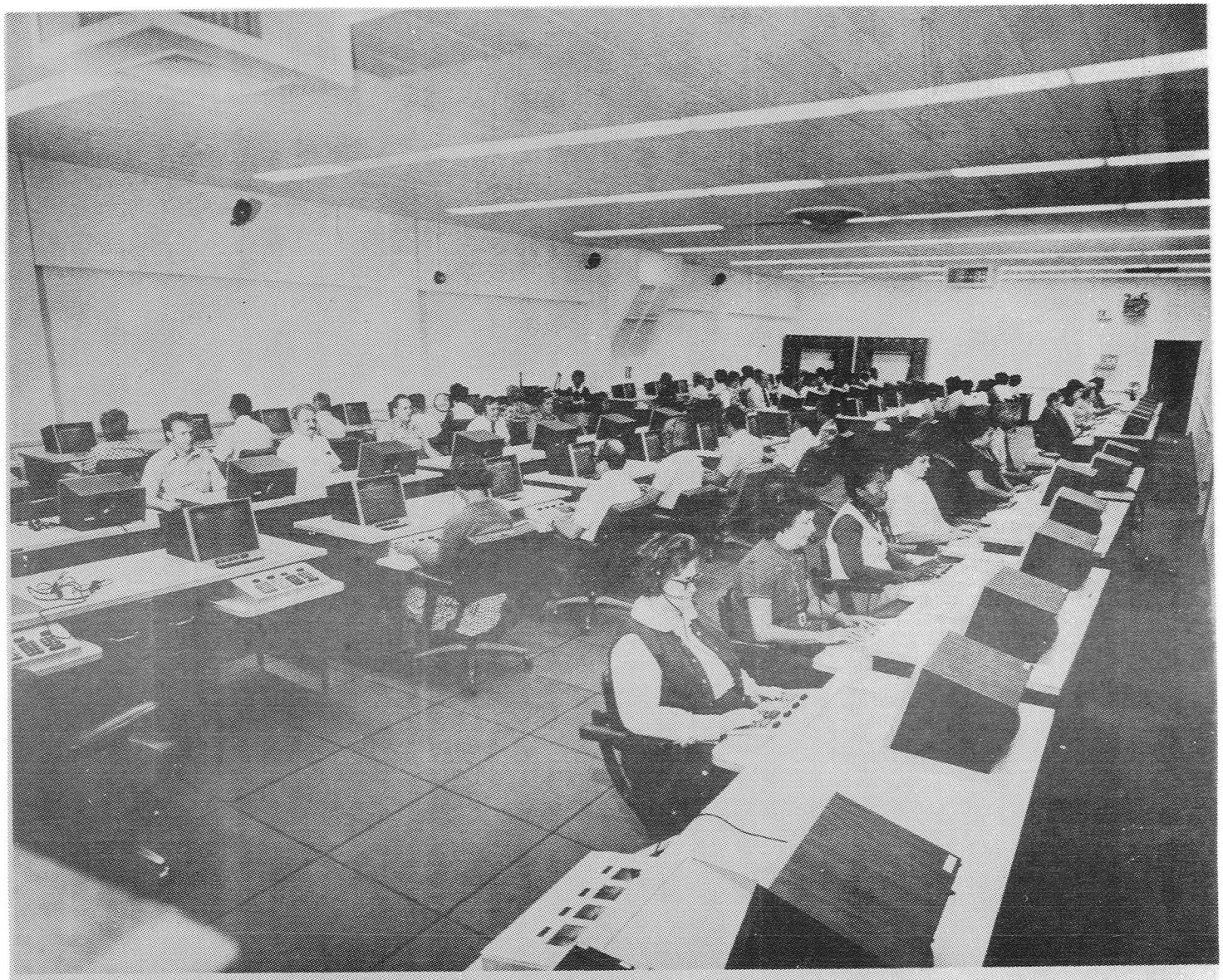

Figure 1.- Federal Aviation Administration Technical Center,
Pseudo Pilot Stations

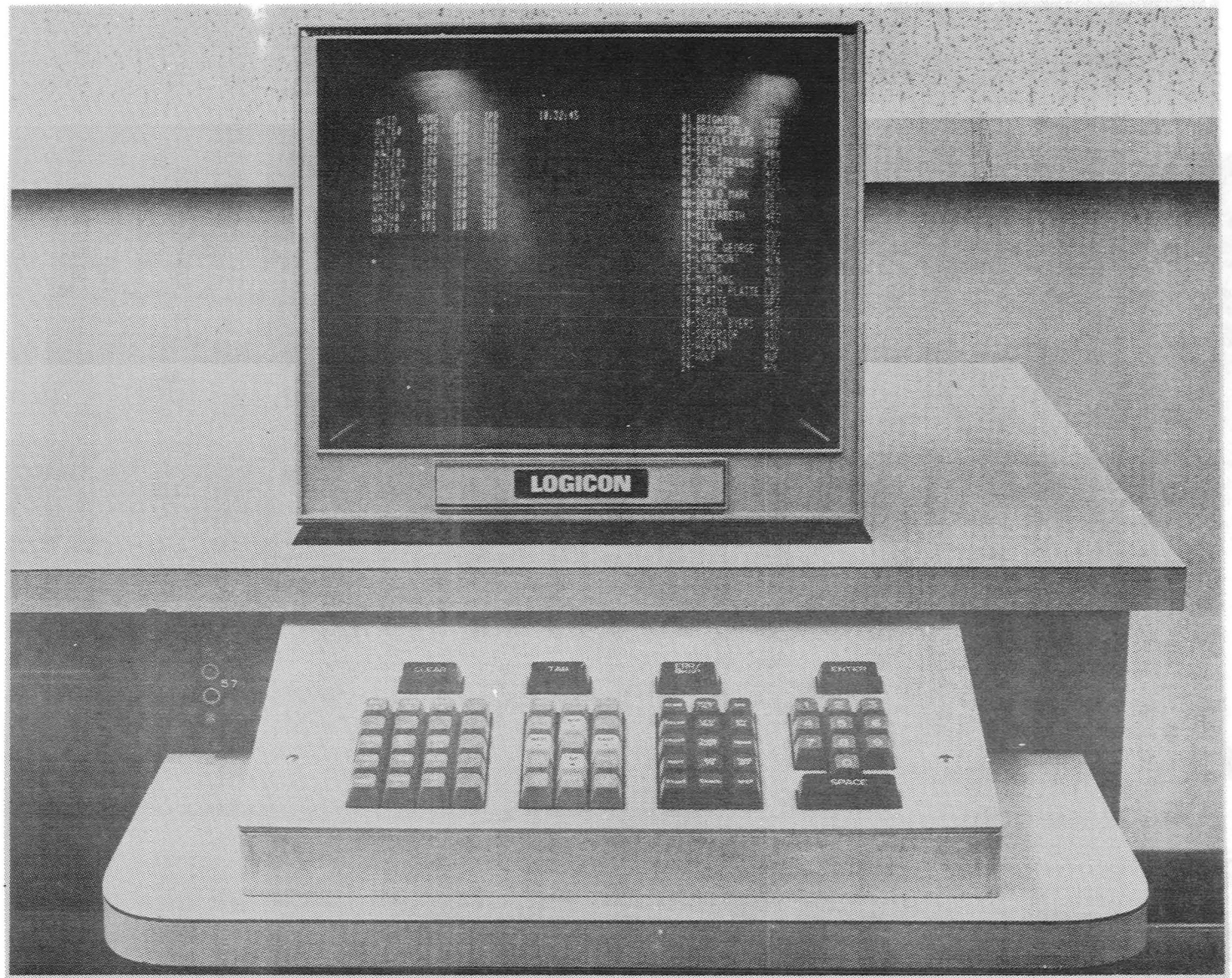

Figure 2.- Closeup of Federal Aviation Administration Technical Center's Pseudo Pilot Station

Figure 3.- Threshold Technology 600 Voice Recognition System

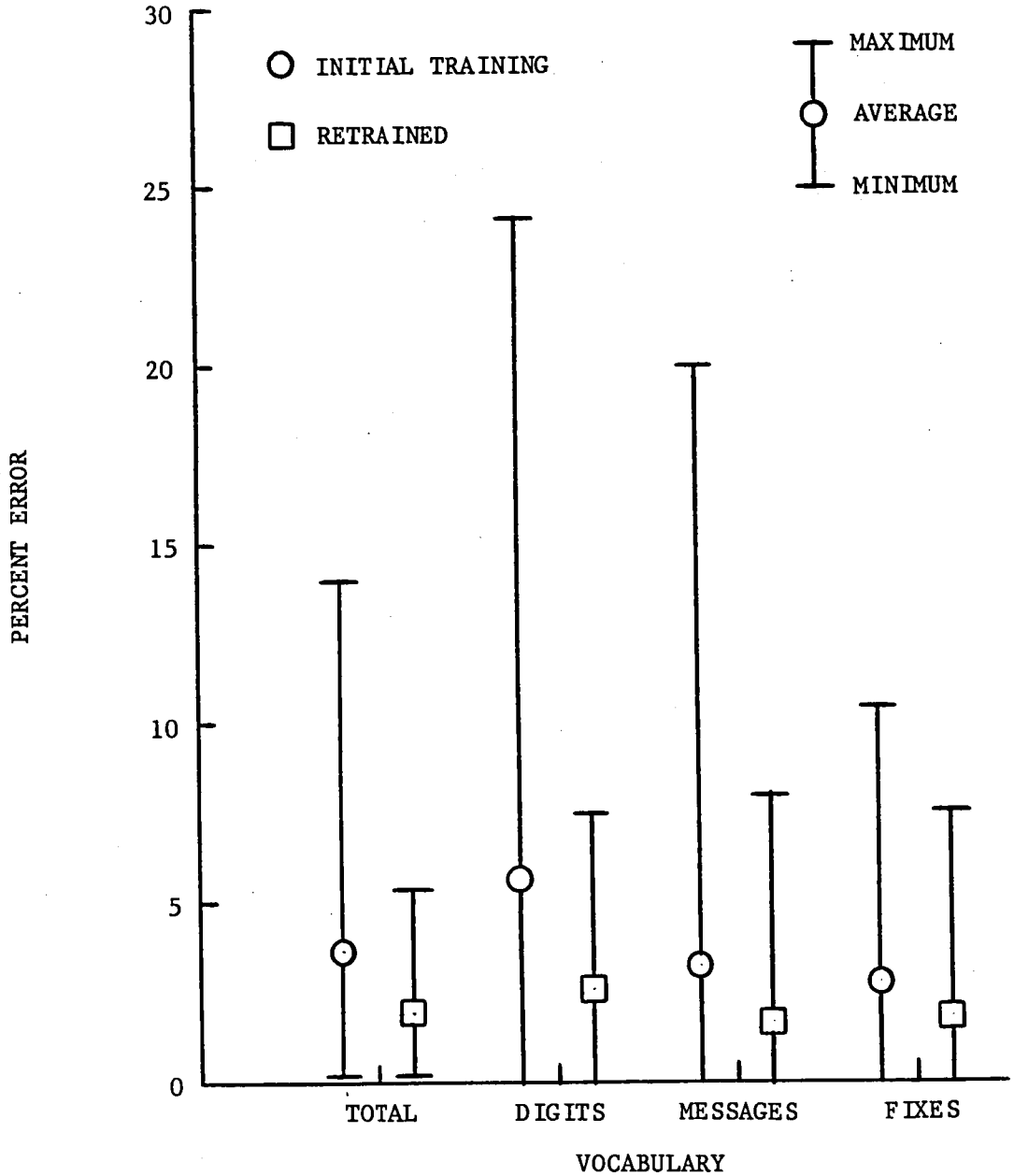

Figure 4.- Subject Group Word Recognition Errors

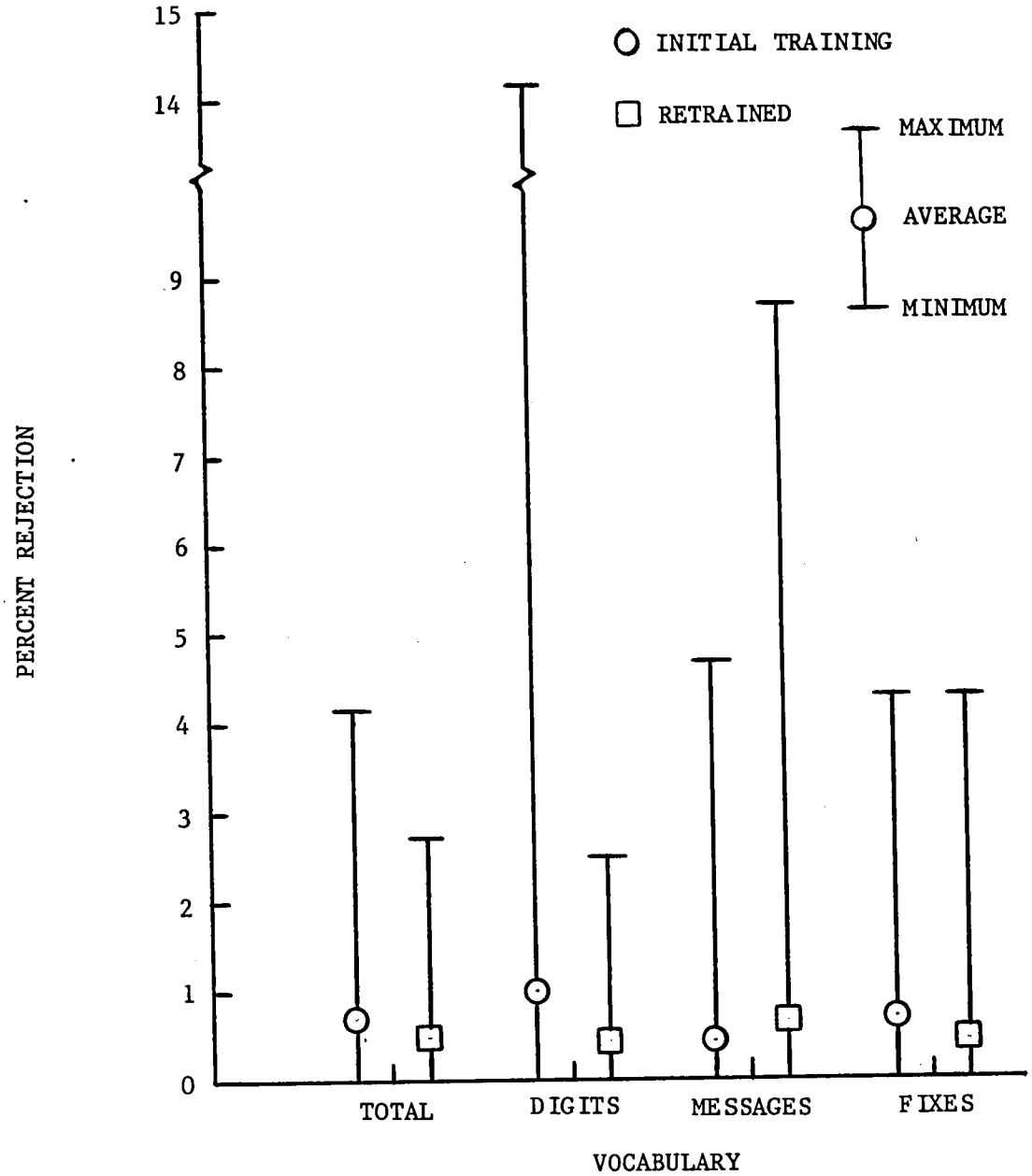

Figure 5.- Subject Group Word Rejection Rate

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15. Supplementary Notes

16. Abstract

The Langley Research Center has undertaken a technology development activity to provide a capability, the Mission Oriented Terminal Area Simulation (MOTAS), wherein terminal area and aircraft systems studies can be performed. An experiment was conducted to evaluate state-of-the-art voice recognition technology and specifically, the Threshold 600 Voice Recognition System to serve as an aircraft control input device for the MOTAS Pseudo Pilot Station function. The results of the experiment using ten subjects showed a recognition error of 3.67 percent for a 48-word vocabulary tested against a programmed vocabulary of 103 words. After the ten subjects retrained the Threshold 600 system for the words which were misrecognized or rejected, the recognition error decreased to 1.96 percent. The rejection rates for both cases were less than 0.70 percent. Based on the results of the experiment, voice recognition technology and specifically the Threshold 600 Voice Recognition System were chosen to fulfill this MOTAS function.

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