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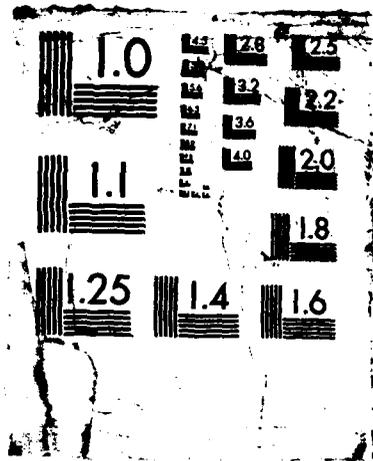
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A COMPARISON OF TWO CHORD KEYBOARD CODING SYSTEMS FOR  
ALPHANUMERIC DATA ENTRY

John Roger Amell  
Eric E. Crawford  
Human Factors Branch  
Crew Systems Division  
Directorate of Support Systems Engineering

June 1987

Final Report

Approved for public release; distribution unlimited.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) > Chord keyboards are alphanumeric data entry devices that generally have fewer keys than a standard typewriter keyboard. Characters are produced by pressing either a single key or several keys simultaneously. Two coding systems, both using one-handed operation, were implemented on a commercially available chord keyboard, the "Microwriter." The coding system resident on the Microwriter was compared to the coding system developed by Sidorsky (1974), known as the Alpha-dot system. Measures of time to learn, time to reach a 35 character per minute criterion entry rate, text entry speed and accuracy, and cognitive workload were collected from two groups of ten subjects. Cognitive workload was measured using two auditory tasks in a secondary task paradigm. The results of initial code learning indicated that the two groups did not differ in the amount of time needed to reach a 95 percent accuracy criterion. The Alpha-dot group was, however, quicker in reaching the 35 character per minute speed criterion. Text entry was measured three times during the experiment. The first test, immediately after initial learning of			
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19. Abstract (continued)

the codes, indicated that the Alpha-dot group was typing at a faster rate, with no difference in errors. The second and third tests showed no differences in speed or accuracy. Based on secondary task performance, the Alpha-dot chord system appeared to require less cognitive workload than the Microwriter chord system.



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TABLE OF CONTENTS

	Page
INTRODUCTION . . . . .	1
History of chord keyboards . . . . .	1
Recent Developments . . . . .	3
Alpha-dot . . . . .	7
Microwriter . . . . .	16
Chord Keyboards vs QWERTY . . . . .	20
Aircraft Applications . . . . .	24
Comparison of Alpha-dot and Microwriter . . . . .	26
Overview of Experiment . . . . .	32
Secondary Task Methodology . . . . .	32
METHOD . . . . .	35
Subjects . . . . .	35
Apparatus . . . . .	35
Procedure . . . . .	36
Initial Keyboard Learning . . . . .	37
Text Entry . . . . .	42
Building Speed . . . . .	42
Artificial Speech Recognition . . . . .	43
Secondary Tasks . . . . .	44
Dual Task Practice . . . . .	45
Dual Task Testing . . . . .	46
RESULTS . . . . .	48

TABLE OF CONTENTS (CONTINUED)

Learning Trials . . . . .	48
Speed Building . . . . .	49
Dual Task . . . . .	52
Secondary Task Scaling . . . . .	60
DISCUSSION . . . . .	63
Learning Trials . . . . .	63
Speed Building . . . . .	64
Dual Task . . . . .	65
Cockpit Implementation . . . . .	67
Other Potential Uses of Chord Keyboards . . . . .	70
APPENDIXES	
A. Instruction to subjects . . . . .	72
B. F-16 Acronyms used in speed building . . . . .	78
REFERENCES . . . . .	81

LIST OF FIGURES

Figure	Page
1. Stewart's ANTEL keyboard layout . . . . .	5
2. IBM Chord keyboard layout. . . . .	6
3. Alpha-dot Character Set . . . . .	8
4. Formatted and free text situation reports . . . . .	12
5. The Microwriter . . . . .	17
6. Microwriter Character Set . . . . .	19
7. QWERTY learning data . . . . .	23
8. Chord vs QWERTY learning . . . . .	25
9a. Training pattern recommended by Microwriter . . . . .	30
9b. Spatially accurate training pattern . . . . .	30
10. Alpha-dot training screens . . . . .	39
11. Microwriter training screens . . . . .	40
12. Graph of number correct on secondary task . . . . .	53
13. Secondary Task Capacity Equivalence Curves . . . . .	62
14. F-16 control panel . . . . .	68

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LIST OF TABLES

Table	Page
1. Alpha-dot verses standard typewriter . . . . .	13
2. QWERTY learning times . . . . .	22
3. Microwriter learning with and without mnumonic cues . . . . .	31
4. Rank Ordered Data for Speed Building . . . . .	51
5. Number of Correct Responses per Minute on Secondary Tasks . . . . .	56
6. Mean Percent Error on Each Keyboard . . . . .	58
7. Mean Percent Error on Secondary Tasks . . . . .	59

## INTRODUCTION

A chord keyboard is a device which can produce all alphanumeric characters using fewer keys than a standard typewriter keyboard. Characters are produced by pressing one key or two or more keys simultaneously. Several chord keyboards have been developed since the 1940's with the number of keys ranging from four to twelve. Some have been designed to operate with one hand; others, such as mail sorting machines are operated with both hands.

The major developmental work in the 1950's and 60's was conducted by the British, Canadian, and American postal services (Noyes, 1983b). These keyboards all required that simultaneous keypresses with both hands be used to enter postal codes. Generally, the chording principle was successful in terms of speed and accuracy (Bowen & Guinness, 1965; Conrad, 1960; Cornog & Craig, 1965; Cornog, Hockman & Craig, 1963; Levy, 1955). Recently, one-handed devices have received attention (Enfield, 1978; Gopher, 1979; Owen, 1978; Rochester, Bequaert, & Sharp, 1978; Sidorsky, 1974).

One of the major advantages of a one-handed chord keyboard is its typically small size. It can be used in spaces too restrictive for a standard keyboard and can also be readily moved over a wide area. In addition, the other

hand is free to be used for additional tasks such holding a telephone, turning pages, etc. From an ergonomic point of view, a chord keyboard does not require the user to maintain an unnatural keying position (both hands directly in front of the body) and does not take up space immediately in front of the operator.

The major disadvantage of using some chord keyboards is that training is required before they can be used, unlike a standard keyboard. Novice users of standard (QWERTY) keyboards can "hunt and peck" to produce characters with no training. The keys of most chord keyboards are unmarked because each key is used in combination with others to produce a given character. New users must learn the codes for the characters before attempting to produce usable work.

Ratz and Ritchie (1961) investigated possible data processing applications of chord keyboards by measuring the relative difficulty of producing the 31 combinations of keypresses possible with one hand. In their experiment, subjects were required to press the keys corresponding to a pattern of lights presented adjacent to the keyboard. Reaction time measures were taken on all combinations of right hand only and both hands together. Chords were rank ordered by reaction time to stimulus patterns. They concluded that the speed attainable on a chord keyboard was primarily a function of the complexity of the motor response rather than by decision time. Unfortunately, it is not possible to separate motor response complexity from stimulus complexity. Regardless of the response required, longer

response latencies would be expected from complex stimuli. They also reported that subjects attained asymptotic performance after two ten minute training sessions. Seibel (1962) replicated the Ratz and Ritchie experiment over a much longer time span and found substantial improvement in reaction times well beyond twenty minutes. However, the rank ordering of chords by reaction times in the two experiments was very similar. Seible (1962) reported a rank order correlation of .896 between his data and the data of Ratz and Ritchie. One problem with predicting typing performance from reaction time experiments such as these is that they ignore the advantage gained by "looking ahead" and the disadvantage of producing chord patterns in rapid succession (Seibel, 1962; Seibel, 1964).

#### Recent Developments

In the past fifteen years, there have been several attempts to develop and produce chord keyboards. The following review will describe Stewart's (1973) ANTEL keyboard, a calculator-like device, Owen's (1978) Writehand, a one-handed keyboard with four finger keys and eight thumb keys, Rochester, Bequaert, and Sharp's (1978) IBM keyboard, a one-handed keyboard using ten finger keys and four thumb keys, Gopher's (1979) Letter-shape keyboard, a four key keyboard for the Hebrew language, Sidorsky's (1974) Alpha-dot keyboard, a five key, two stroke per character keyboard and Enfield's (1978) Microwriter, a keyboard using four finger keys and two thumb keys.

Stewart (1973) patented his ANTEL keyboard, twelve closely spaced marked keys arranged alphabetically in a 4 X 3 matrix. A total of 36 characters could be produced by pressing one, two, or four keys simultaneously with one finger. The top row of the keyboard contained the "A", "C" and "E" keys. Pressing one of these keys produced the indicated character. A "B" was produced by one finger simultaneously pressing the "A" and the "C" keys; and a "D" by pressing the "C" and "E" keys. A "G" was produced by pressing four keys simultaneously, "A", "C", "K", and "M". The rest of the alphanumeric characters were produced in the same manner, as can be seen in Figure 1. No performance data has been reported for the ANTEL keyboard.

The "Writehander" is a hemispherically shaped one-handed chord keyboard having four finger keys and eight thumb keys and is capable of producing the entire 128 characters of the ASCII code. Owen (1978) intended this device to be used as a computer interface. Again, no performance or learning data have been published.

Rochester et al. (1978) developed a one-handed chord keyboard for IBM that uses a 5 X 2 matrix of ten square keys operated by the fingers and four rectangular keys operated by the thumb. This keyboard is shown in Figure 2. The IBM keyboard operates similarly to the ANTEL keyboard in that one stroke of one finger can press up to four keys simultaneously. The finger keys have dimples in the surface which, when the dimples are pressed can cause one, two, or four keys to be activated. The keyboard is divided into

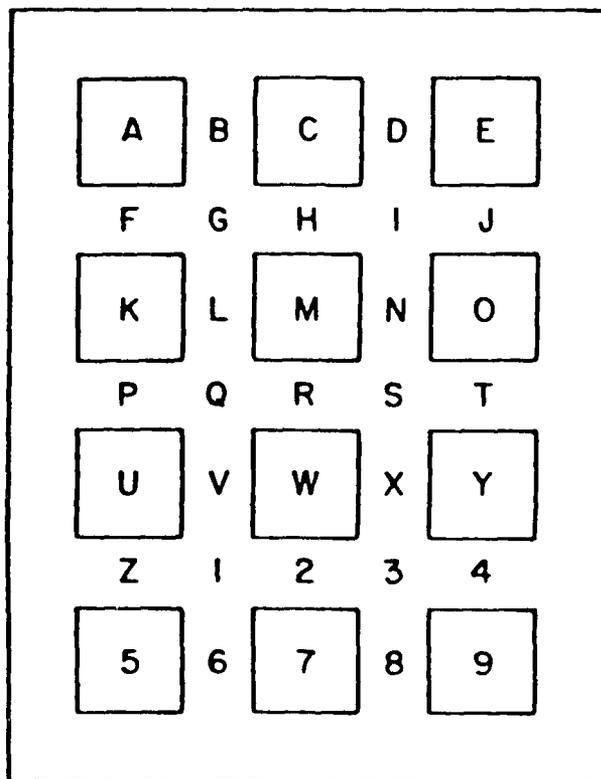


Figure 1. Stewart's ANTEL keyboard layout.

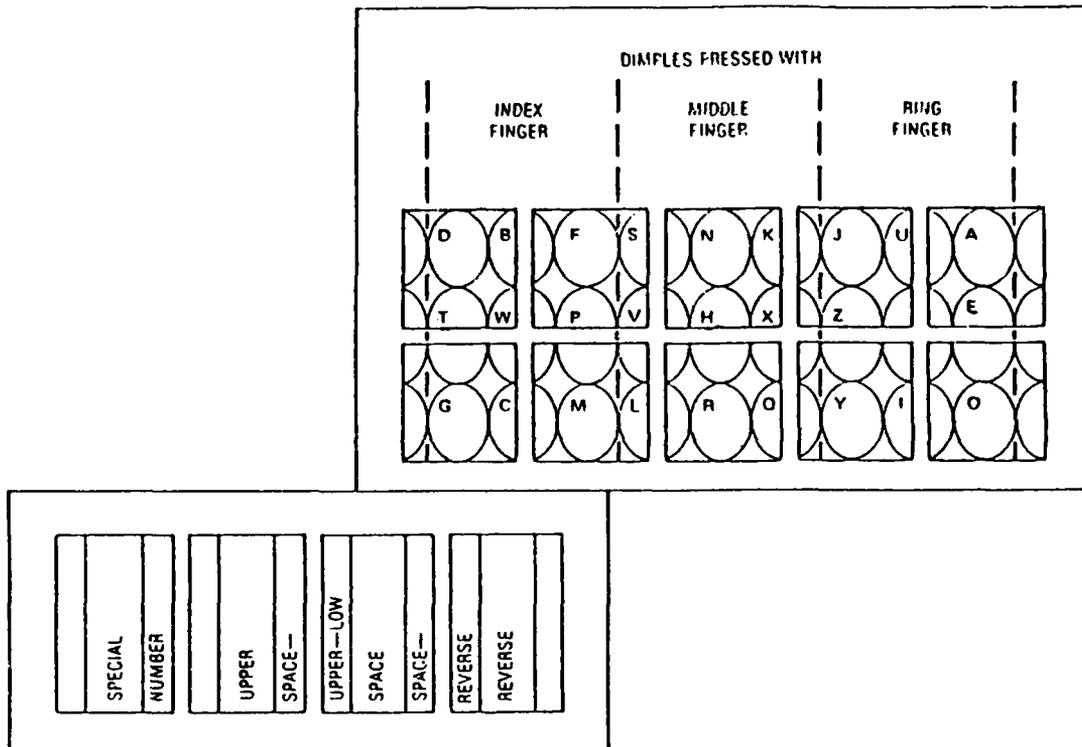


Figure 2. IBM chord keyboard layout.

groups of dimples to be pressed with the forefinger, middle finger, or the ring finger. The IBM keyboard differs from ones previously discussed by having the capability to type common digrams and trigrams with a single stroke of two or three keys. Rochester et al. (1978) reported the results obtained from training a group of four students to use the IBM chord keyboard. The four students were trained using an automated system developed for that purpose. After using the system for four to five hours per week for nine months, three of the four students were typing at a rate of approximately 40 words per minute. The fourth student reached a rate of approximately 25 words per minute. These rates were achieved while typing new material with no more than two errors per minute. No IBM machine has yet been marketed using this chord keyboard.

Sidorsky (1974) introduced his "Alpha-dot" system, a two stroke per character chord keyboard, as an data input device alternative to conventional techniques such as standard keyboards, push buttons, rotary switches, and sliding switches. The system was designed primarily for computer input of battlefield data from multiple sources in the field during real-time tactical operations. Sidorsky proposed using the Alpha-dot system to solve the problem of excess time delays between scouting reports of enemy activity and computer access to that information.

The Alpha-dot system is based upon a specially designed set of alphanumeric characters (Figure 3). A spatial mnemonic was developed so that the shape of the character

A	B	C	D	E	F	G	H	i	j
K	L	M	N	O	P	Q	R	S	T
U	V	W	X	Y	Z				
0	1	2	3	4	5	6	7	8	9

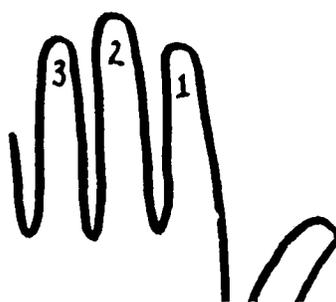
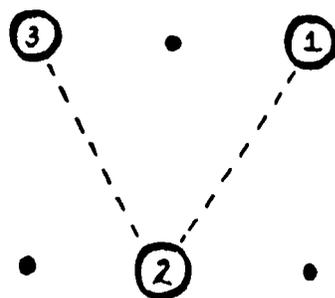


Figure 3. Alpha-dot character set.

determined which keys to press. Data entry is accomplished by keypresses using the fingers of one hand, either singly or in combinations of up to three fingers at a time. Each character requires two keystrokes. The three center keys of the five key keyboard, the character keys, correspond to the three dots in each horizontal row of the Alpha-dot character matrix. Each horizontal row of dots correspond to a single stroke. As can be seen in Figure 3, the first keystroke corresponds to the upper portion of the character and the second stroke represents the bottom portion. All letters and digits were entered using only the three character keys. For example, the letter "V" is represented by the left and right top dots and the middle bottom dot. Therefore, it is entered by pressing both the left and right keys simultaneously with the forefinger and the ring finger for the first stroke (representing the left and right top dots) and the middle key with the middle finger for the second stroke (representing the middle bottom dot). The thumb and little finger keys were used only for punctuation marks, mathematics symbols, and machine operation commands (ie tab, carriage return, etc.) Sidorsky argued that by using shape coding, characters should be easy to learn and remember.

Although 31 unique chords are possible with five keys using a single stroke, the Alpha-dot system uses only three keys in character construction. Only seven unique key combinations can be generated with a single stroke of three keys. Using the two stroke approach, a character set size of 49 (7x7) can be generated. If the combinations using the

of 49 (7x7) can be generated. If the combinations using the thumb or little finger keys for one stroke are included, the character set size can be expanded to 81.

An experiment reported by Sidorsky (1974) collected data on learning times and speed of data entry using the Alpha-dot coding system. Ten enlisted Army personnel practiced on the keyboard for five hours distributed over a 10 to 15 day period. Practice was in four phases. In phase one, subjects were given a five minute introduction to the Alpha-dot system. They then entered the entire character set with the aid of a large chart depicting the coding scheme. The keypresses were fed into a CDC 3300 computer where they were translated and then displayed on a CRT, providing immediate feedback to the subject. Each character was entered ten consecutive times. Then, the entire character set was practiced one at a time followed by entering simple sentences such as "the quick brown fox jumped over the lazy dog's back."

During phase 2, the subjects again entered the entire character set plus the "quick brown fox" sentence, but this time without the aid of the chart. Error correction was allowed by backspacing and retyping a character. If a subject forgot a character he or she was shown the chart. Phase 2 was complete when the subject entered the complete character set and the "quick brown fox" sentence twice without error.

Phase 3 was similar to phase 2 except that the CRT was removed. Errors were reported to the subjects by the

experimenter. Phase 3 was complete when the subject was able to enter the entire character set plus the "quick brown fox" sentence twice without error. At this point, the character set was considered to be learned and the subjects were told to maximize their speed.

The final phase consisted of entering sample battlefield messages. Both formatted and free text messages were used. Sample messages are presented in Figure 4. All of the messages contained every letter and digit so that any forgetting of the code would be detected. Twenty different messages of each type were entered each day. After the subjects became reasonably proficient in entering both types of battlefield messages, they were instructed to enter the same type of messages on a standard computer keyboard attached to the CRT. This enabled a direct comparison between the Alpha-dot keyboard and the standard procedure. Although it was not reported if subjects knew how to "touch type", subject's typing rates on the standard typewriter ranged from 54.5 CPM to 176.5 CPM for mixed alphanumeric data.

Nine of the ten subjects learned the entire character set (completed phase 2) within one and one-half hours. The remaining subject learned within three hours. Error rates for both the Alpha-dot and the standard keyboard were very low because subjects were allowed to correct detected mistakes. Therefore, errors were not included in the analysis. Data entry rates obtained for both the Alpha-dot and standard keyboards are shown in Table 1.

FORM: W 2    PREC: R    SEC: U N C    ORIG: K 9  
UNIT: U K \_ 3 R D \_ G U A R D S    TYPE: E N G    SIZE: B A I  
ACT: L E A V I N G    LOC: M Q 1 6  
PERS: 4 8 0    WEAP: H O W    TIME: 1 9 1 5    DATE: 0 5 1 7 7 2  
CO-1: E 3 8 X 7 6    CO-2: P 6 3 Z 7 8    CO-3: Y 4 0 J 2 2

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Figure 4. Formatted and free text situation reports.

TABLE 1

Data Entry Rates for the Alpha-dot Keyboard and the Standard Keyboard

Material	Keyboard	Entry Rate
All Letters	Alpha-dot Keyboard	65.25 CPM
Mixed Alpha/Numeric Text	Alpha-dot Keyboard	63.0 CPM
	Typewriter	116.5 CPM
Mixed Alpha/Numeric Formatted	Alpha-dot Keyboard	54.5 CPM
	Typewriter	52.0 CPM

The maximum rate of data entry for any subject was reported to be 86 CPM. This rate was achieved on the "quick brown fox" sentence. The results indicate that the Alpha-dot keyboard is comparable to a standard keyboard especially when the data are highly formatted. The subjects entered the formatted data with the Alpha-dot keyboard at approximately the same rate as they did with the standard keyboard. Sidorsky concluded that the Alpha-dot system appeared to have potential to increase the speed, accuracy, and flexibility of the input of battlefield data by frontline observers.

Gopher and Eilam (1979) modified Sidorsky's two stroke chord approach to design a Letter-shape keyboard for the Hebrew language. The characters in the Hebrew alphabet are based on square figures with most of the distinguishing features located on the top and bottom. These features make Hebrew more adaptable to the Alpha-dot approach than English. In addition, the first ten letters of the Hebrew alphabet correspond to the digits 1 to 0, so there was no need to have unique codes for numbers.

The Hebrew Letter-shape keyboard consists of four keys. The three leftmost keys, operated by the forefinger, middle finger, and the ring finger, are used to construct the characters. The fourth key, operated by the thumb, is used for cursor control and editing functions. Like the Alpha-dot keyboard, the Letter-shape keyboard constructs characters with two strokes, the first for the upper portion of the character and the second stroke for the lower part.

A series of experiments were conducted to determine the

Letter-shape keyboard's suitability for use as a cockpit data entry device for the Israeli Air Force. Gopher and Eilam (1979) reported that an "average" subject could learn the code in 5-10 minutes, but no data were presented. The short learning times were attributed to the close correspondence between the printed Hebrew and the Letter-shape code. Training was needed primarily to increase speed and efficiency of entry, and to reduce the cognitive load on the processing system.

Experiments 1 and 2 focused on the learning, retention, and speed of entry. The subjects in their Experiment 1, five right handed Israeli Air Force Reserve soldiers, reached an entry speed of 65 characters per minute after seven hours of training. Error rates were stable at 1 percent after two hours of training. Retention was tested after a six week period without practice. Performance did not seriously degrade over the six week interval. Speed scores dropped less than ten CPM, but errors were not reported. Within an hour, the subjects had equaled their previous speed and accuracy scores. In their Experiment 2, the entry of text was compared with the entry of sequences of five-character nonsense words. After six hours, six student volunteers were entering text at the rate of 56 CPM compared to a rate of 41 CPM for the nonsense combinations.

Experiment 3 investigated data entry with the Letter-shape keyboard during a flying task. After three hours of keyboard training, four pilots flew two missions in a Singer-link, six degree of freedom motion-based F-4

simulator. The subjects were read sentences that had to be entered with a Letter-shape keyboard which was strapped to their left leg. All data entry was performed with the left hand, because the right hand operated the stick. Speed and accuracy of text entry during flying (dual task performance) were compared with performance on these measures while not flying, but sitting in the simulator (single task performance). Flying performance also was recorded to check for any decrements due to keyboard operation.

The subjects were trained using their left hand, and reached a rate of 53 CPM after the three hour training period. No reliable differences were found in data entry rates or errors between the single and dual task performance conditions and no decrements were discovered in flying performance. However, for experienced pilots, flying by itself has not been found to be a task with a particularly demanding cognitive load (Colle and Demaio, 1978).

Gopher and Eilam concluded that the Letter-shape keyboard appears promising as a means of cockpit data entry. Its small size and short training times make its incorporation into fighter cockpits feasible.

Enfield (1978) developed the "Microwriter" as an alternative to a standard typing keyboard. This device is a self-contained interface device with 4K of memory, internal or external power supply, a 16 character LCD display, and an RS-232 communication port. The Microwriter, shown in Figure 5, differs from the Alpha-dot and Letter-shape keyboards in several ways. The five character keys are arranged to fit

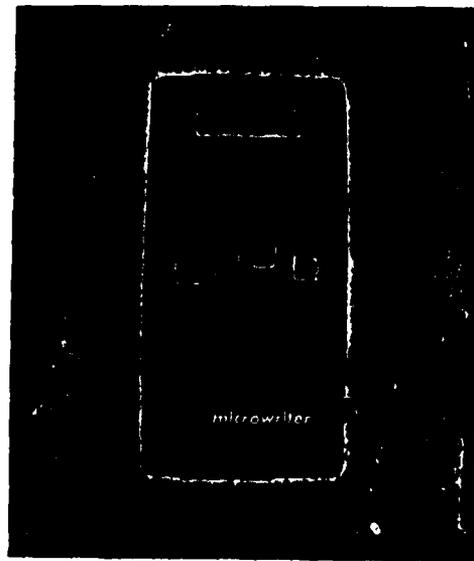


Figure 5. The Microwriter.

the hand, and all five are used in character construction. A sixth control key is located below the thumb key and is used to change operating modes. Available modes include lower case alpha, upper case alpha, numeric and punctuation. The Microwriter's characters are produced with single strokes of one or more keys. This system reduces the gross motor requirements to produce a character since only one stroke is required but since all five fingers are used in character construction, the coordination difficulties (fine motor requirements) increase. The coding strategy attempts to visually match each character with its code as shown in Figure 6. A set of mnemonic cues was designed to help new users learn the coding scheme.

Wheeler (1980) reported an informal study of the Microwriter's capabilities. Seven lecturers and two secretaries from Newcastle-upon-Tyne Polytechnic were given a two day introductory course in the use of the Microwriter. The lecturers then used the Microwriter to prepare student handouts and lecture notes for four months. No attempt was made to control the test environment and the actual means and ranges of learning times were not reported. At the end of the test period, most of the users were typing at a rate of 60-75 characters per minute (CPM), but no indication was given of the actual number of hours of practice. Wheeler concluded that the Microwriter was reliable mechanically as well as being highly portable. He also found it to be popular with the participants and easy to learn and use.

Shackle (1983) reported a study comparing the

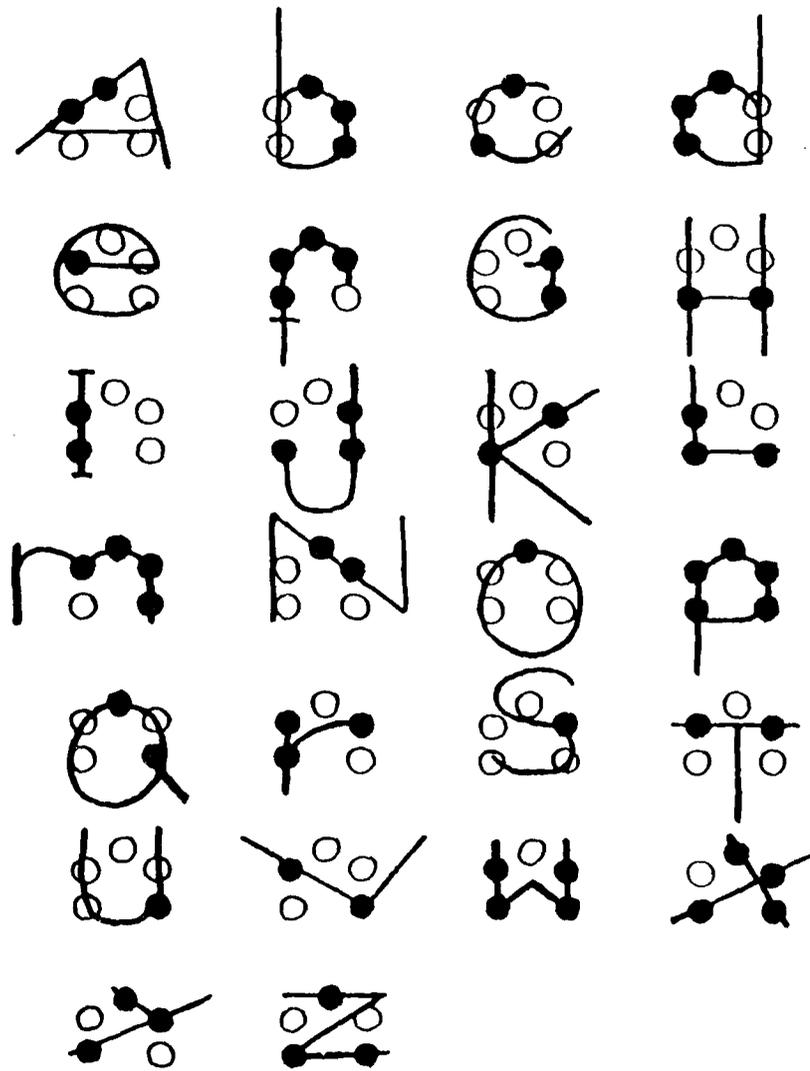


Figure 6. Microwriter character set.

Microwriter and the Maltron one-handed sequential keyboard. After approximately nine hours of practice, the two Microwriter groups were typing text at mean rates of 57.1 and 53.9 CPM. Differences in training procedures and material made comparisons between the two keyboards difficult and no differences were found.

At this point in time, there has not been enough research on chord keyboard training and performance to draw firm conclusions regarding their applicability to data processing. There are also few skilled operators of any chord keyboard on which to collect data on the maximum rates attainable.

#### Chord Keyboards vs QWERTY

Although QWERTY keyboards have been in use since the late 1800's, very little controlled research has studied learning and performance on QWERTY keyboards. Noyes (1983) reported that touch typing courses such as "Sight and Sound Education Limited" can teach novices to type at a rate of 100 Characters per minute in 12 hours. Nothing is mentioned, however, about the type of material used for testing, or the duration and frequency of the lessons. Conrad (1961) has shown that type and difficulty of material is a major determinant of typing speed.

Robinson and Trebbi (1976) described a survey of 4000 high school student's performance in a typing class. They reported that students were typing at an average rate of 95-130 characters per minute after 6 weeks of classroom

training. After 36 weeks, the students were typing at a rate of 175-225 CPM. Again, the type of material and duration and frequency of practice sessions were not described in detail. Green (1940) also reported the time needed to learn to type in terms of weeks in class rather than the actual time spent performing the task and reported similar data. It is difficult to draw conclusions based on studies where the participants have varying amounts of practice.

Baddeley and Longman (1978) reported one of the few carefully controlled studies on learning to type on a standard QWERTY keyboard. Four groups of eighteen subjects each were taught to type in order to study the effects of practice distribution. The distribution of practice varied as follows: 1) The 1x1 group received one hour of practice once per day 2) the 1x2 group received one two hour session per day 3) the 2x1 group received two one hour sessions per day and 4) the 2x2 group received two two hour sessions per day. All groups used the same materials and training procedures. Training was divided into two parts, initial keyboard learning and speed practice. The results of the learning task are presented in Table 2. Once the keyboard was learned, speed tests were given once each hour thereafter. The resulting learning curves for the four groups are shown in Figure 7. The 1x1 group learned the fastest and maintained the advantage throughout the remainder of the experiment and the 2x2 group learned the slowest. However, the rate of improvement during speed testing was the same for all groups except the 2x2 group.

TABLE 2

Mean number of hours to learn the keyboard as a function of training schedule, range in brackets (from Baddeley and Longman (1978))

Hours per Session	Sessions per day		Mean
	1	2	
1	34.9 (26-44)	42.6 (34-46)	38.8
2	43.2 (37-45)	49.7 (46-54)	46.4
Mean	39.5	46.2	

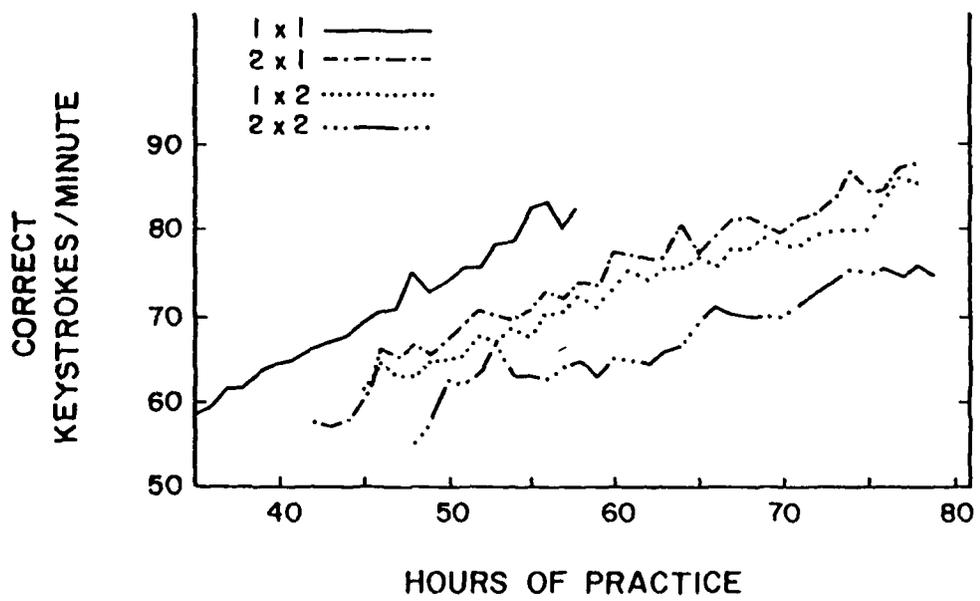


Figure 7. QWERTY learning data  
 (from Baddeley and Longman, 1978)

In a study reported by Conrad and Longman (1965), two groups of postmen who had never used a typewriter were trained on either a standard QWERTY keyboard or a two-handed chord keyboard. Both groups used the same training material after the initial keyboard training. The goal was for both groups to learn the keyboard as fast as possible so that at the earliest time both groups could be tested on identical material. Both groups received 2 training sessions per day of 1.5 hours each, 5 days per week for 7 weeks. The chord keyboard group learned their keyboard in an average of 12.5 days and were typing at a rate of 55.1 CPM at the end of training. The typewriter group learned to type in an average of 21.2 days and were typing at an average rate of 65.6 CPM at the end of training. Although the typewriter group was typing faster at the end of initial keyboard training, it took them 9 more days to learn the keyboard. From the time where direct comparisons were possible, after both groups completed initial training, the chord group was typing faster than the typewriter group, as can be seen in Figure 8.

#### Aircraft Applications

One-handed chord keyboards have possible cockpit applications, especially in small, high speed aircraft such as fighters. The data entry task in an aircraft is currently a head-down operation, meaning that the pilot must look away from the outside world. At the speeds and altitudes flown today, this is undesirable. Since the chord keyboard is inherently a touch typing machine, data entry becomes a

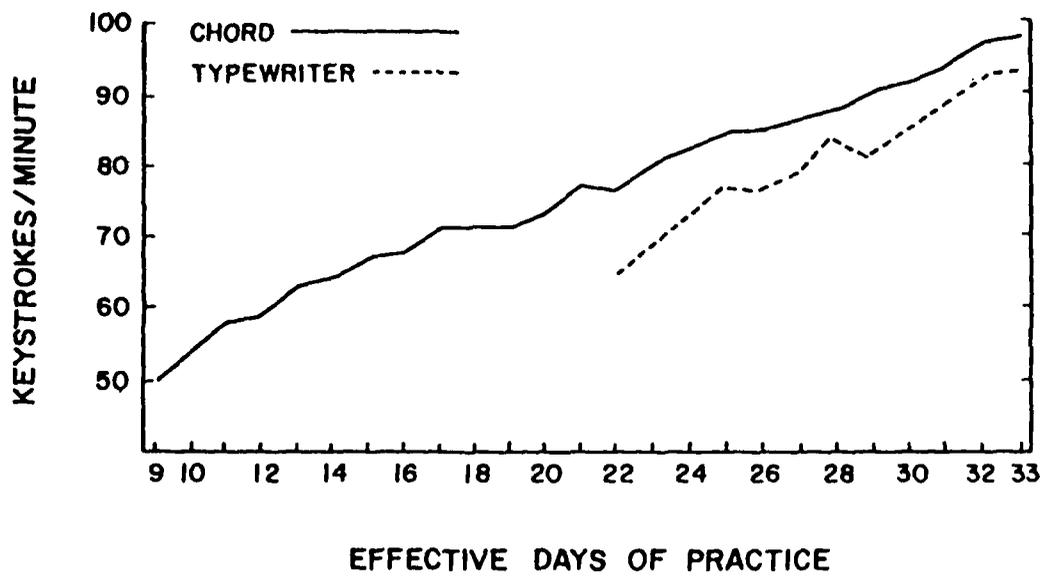


Figure 8. Chord vs QWERTY learning data  
(from Conrad and Longman, 1965)

head-up task. Possible objections to the use of these keyboards is the amount of training required, code retention, and the amount of cognitive loading imposed on the operator. The issue of training time is important because training pilots is already an expensive and time consuming task. Anything that negatively affects training time compounds the problem. A lack of code retention could have serious implications in the cockpit. If a pilot forgot the code for even one character, it could mean that he could not access that system or make a necessary change. Although a list could be made available depicting the letters and their codes, its use would compromise any benefit derived from head-up data entry. The cognitive loading produced by operating a chord keyboard is another important factor. The amount of cognitive workload associated with the operation of a device affects a person's ability to perform concurrent tasks. Since an aircraft cockpit is a multi-task environment, it is critical that tasks be designed to produce a minimum of interference with one another.

#### Comparison of Alpha-dot and Microwriter

Learning times, measures of retention, and cognitive workload measures are needed to ascertain if chord keyboards have potential for aircraft cockpit data entry devices. The current research collected data on the learning times, accuracy, and cognitive workload for two different coding strategies, the Microwriter's and Alpha-dot's. These two were chosen because of their similarities and their

differences. Both are one-handed devices that require minimal if any movement of the fingers between keys, but they differ in how they handle the problem of how to construct a character set containing 36 or more characters when only 31 different combinations of five keys are available. The Microwriter added a sixth key to switch between alpha and numeric modes while the Alpha-dot system added a second stroke to each character to expand its maximum number of unique combinations to 81.

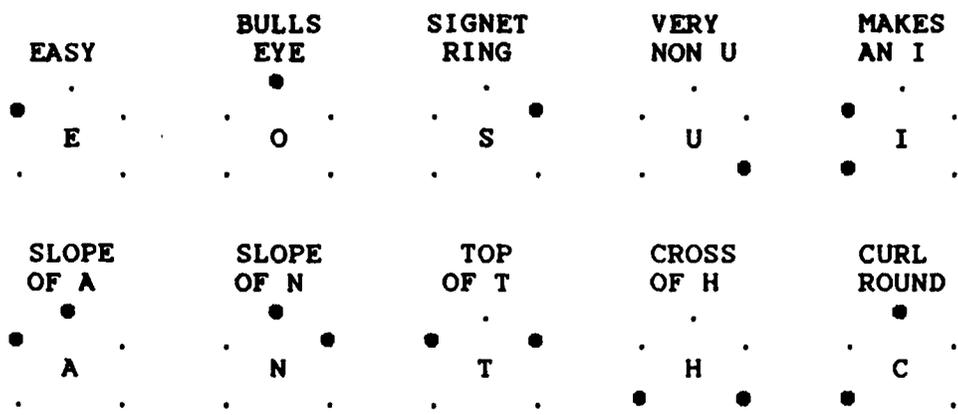
The subjects in this experiment were required to sit at a computer terminal and learn one of the coding strategies with the help of on-line computer instruction, similar to typing tutor programs. Sequences of alphanumeric characters appeared on the CRT display and the subjects were required to type the identical sequence directly below it using their left hand.

Left-handed operation has no effect on the Alpha-dot coding scheme. The code is based on the spatial position of the characters without reference to what fingers are used to produce those characters. Since only the three middle fingers are used to enter character codes, there are negligible finger coordination problems. Changing from right to left-handed operation only requires switching the ring finger and forefinger positions. Since the Microwriter uses all five keys to construct the characters, the same is not true for its coding. In models made available by the manufacturer, the left-handed coding scheme is a mirror image of the coding for right-handed operation. For example, in

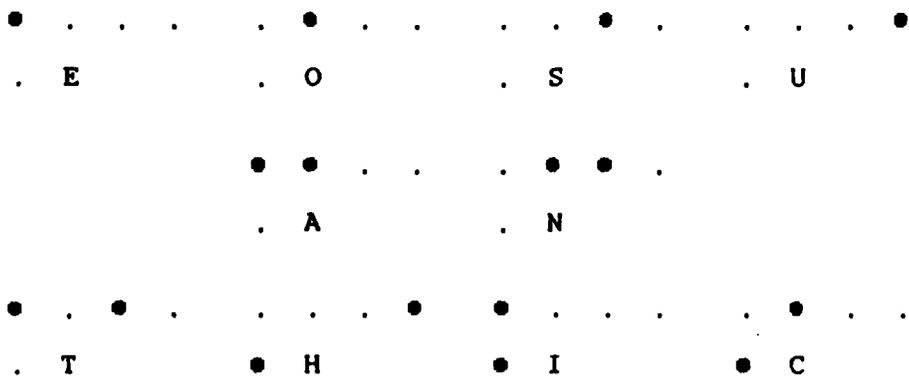
the right-handed version, an "E" is produced by depressing the forefinger and in the left-handed version, an "E" is still produced with the forefinger, but the forefinger no longer has the spatial position shown in Figure 6. This mirror imaging makes many of the mnemonics inappropriate. The code is based on ease of finger coordination for the right hand rather than spatial location, although most of the mnemonics are spatially oriented.

A preliminary study was conducted to investigate the usefulness of the mnemonics as a learning aid. Two groups of eight subjects learned to operate the right-handed Microwriter. One group learned the coding strategy with mnemonics and with the stimulus pattern recommended by the manufacturer (Figure 9A) and the other group learned the coding system without mnemonics and with a pattern recommended by the author (Figure 9B). The latter presentation is more spatially accurate. No reliable differences were found between the two groups. Both time in minutes to reach the 95 percent accuracy criterion,  $t(1,14)=0.91$ ,  $p>.05$ , and number of trials to the 95 percent accuracy criterion,  $t(1,14)=0.27$ ,  $p>.05$  were not statistically significant. Table 3 presents the mean learning time to criterion, mean number of trials to criterion, and the mean number of characters entered per minute for the two groups averaged over all trials. Although subjects in the mnemonic group stated that they thought the mnemonics helped them remember the code, their performance was not different than the group without mnemonics.

Therefore, in this study comparing the Alpha-dot and Microwriter keyboards, the Microwriter lessons used the spatially accurate presentation.



(a)



(b)

Figure 9. Training patterns: a) recommended by Microwriter and b) spatially accurate.

TABLE 3

Comparison of Learning the Microwriter with and without Mnemonics

	Mnemonics	Spatial
Learning Time in minutes	46.2	57.0
Trials to 95%	53.9	58.1
Characters per Minute	31.6 cpm	30.7 cpm

## Overview of Experiment

Subjects were divided into two groups, the Alpha-dot and Microwriter groups, and were tested using three types of material, randomized alphanumerics, text, and simulated aircraft commands. The aircraft commands consisted of three letters followed by three digits. Data was collected on learning, accuracy of data entry and rate of entry in characters per minute. Subjects also performed a data entry task while simultaneously performing one of two secondary tasks, both auditory classification tasks, in order to measure cognitive workload.

Secondary task methodology. Secondary task measures are generally more sensitive to variations in workload than primary task measures (Eggemeier, 1981). Primary task measures, which measure operator performance on a task, can be used to determine if an operator overload condition is present, but cannot distinguish differences in workload below that point. The subsidiary task technique, one version of secondary task methodology, measures operator performance on two concurrently performed tasks, with emphasis being placed on the primary task. The level of performance on the secondary task when performed alone is then compared to the level of performance for the same task when performed concurrently with the primary task. The difference in the performance on the secondary task between the two conditions is then taken as the measure of workload. What is measured is the residual processing capacity of the operator or "how

much additional work the operator can undertake while still performing the primary task to meet system criteria" (Knowles, 1963). According to Knowles, desired characteristics of secondary tasks include non-interference, simplicity, and self-pacing.

Non-interference of the secondary task with the performance of the primary task is crucial to the interpretation of results. Interference or intrusion refers to a change in primary task performance when performed in conjunction with the secondary task. When the performance of both primary and secondary tasks are allowed to vary, then the secondary task does not represent a pure index of the reserve capacity associated with the primary task (Eggemeier, 1981).

Secondary tasks should be simple and require very little learning. As a result of being simple, they should also show very little inter-subject variability. Knowles (1963) suggests that learning effects can be minimized by practice on the secondary task alone and that subject differences can be controlled by establishing a baseline of performance for each subject. An individualized loading index can then be obtained by comparing single and dual task performance on the secondary task.

Knowles (1963) also suggests that secondary tasks be self-paced, meaning that the operator determines the rate of presentation of the task. This allows the operator to adjust the amount of attention given to the secondary task to be compatible with the demand of the primary task.

A method which satisfies these requirements and which, in addition, leads to a standard metric for mental workload or capacity has recently been developed (Colle, 1980; Colle and Ewry, 1986). This dual task technique generates secondary task performance indices which can be referenced to the performance index of a standard task so that different secondary task measures can be compared. This secondary task measurement system also incorporates tests of the additivity of the underlying dimension of capacity. The technique has been used to demonstrate that a wide variety of cognitive classification tasks are additive on a single dimension of capacity (Colle, 1980; Colle and Ewry, 1986).

## METHOD

### Subjects

The subjects for this experiment were obtained by advertising for subjects to participate in psychological experiments posted on the campus of Wright State University. Twenty right-handed males were randomly assigned to one of two keyboard groups. Subjects were paid \$4.00 per hour for their participation.

### Apparatus

The chord keyboard used in this experiment was a Microwriter device modified for left-handed use. The Alpha-dot coding strategy was implemented through software within the instruction and testing programs. For the Microwriter group, the five keys, corresponding to the five fingers, were arranged in the reverse order compared to the right-handed version so that the same fingers were used in character construction for either hand. The sixth key on the keyboard, located below the thumb key, was used to switch between the alphabetic and numeric modes. Mode changes could be made two ways. One press of the mode key would switch to numeric mode for the next character only while two presses of

the mode key would lock in numeric mode until it was manually released by pressing the thumb key and the mode key simultaneously. The instruction and testing programs were run on a microprocessor connected to the chord keyboard via an RS232C interface. An Amdek color monitor (Color IV) was used for presentation of all visual stimuli. The characters were presented in green on a dark grey background. A second microprocessor was used to control the auditory secondary tasks used in the dual task trials.

Synthetic speech was generated using a Computalker board (# CT-1). Subjects responded to the auditory stimuli with a hand-held controller connected to the microprocessor via a RS-232 serial interface. The controller consisted of two .375" diameter round switches mounted in a wooden grip. The forefinger button and thumb button were used to respond "yes" and "no" respectively. Auditory stimuli were presented through Telephonics TDH-39 earphones mounted in MX/41 cushions. A foot pedal was used to start each task or combination of tasks.

#### Procedure

The experiment was divided into two main sections, keyboard learning and dual-task testing for cognitive workload. The keyboard learning section included initial learning of the codes for the character set, a speed building routine used to increase data entry speed until a typing rate of 35 characters per minute was reached, and three text entry tests. The dual-task testing included training on the

recognition of artificial speech, practice on two auditory classification tasks, practice performing the data entry task and one of the auditory classification tasks simultaneously, and the actual dual-task testing.

Initial Keyboard Learning. Subjects were required to learn one of the coding strategies. A computer-aided instruction program was developed to teach the subjects both the Alpha-dot and the Microwriter coding systems. All keyboard entries were performed with the left hand in order to more closely represent actual cockpit data entry procedures. Pilots normally keep their right hand on the control stick. Three two hour training/testing sessions were scheduled over 3 consecutive days. Since the training was self-paced, not all subjects required the full six hours.

The character set to be learned consisted of the ten numbers, the period or decimal point, and the nineteen most frequently used letters in written English text. The letters J, K, Q, W, X, Y, and Z were not used. The character set was divided into three lessons of ten characters each. A training screen, showing the ten characters in the lesson and their code, was presented for 20 seconds prior to each trial. Subjects were encouraged to practice the codes while the training screen was displayed. The results of their keypresses were displayed on the bottom line of the screen. The training screen was followed by a recall test trial. Two seconds prior to the beginning of a trial, a ready signal was presented, replacing the practice screen. The stimuli for

each trial consisted of the ten characters in a randomized order presented in the center of the screen. Subjects were required to match each character in the list on a line directly below it. Subjects were not allowed to correct errors. After the first ten characters were entered, the screen was cleared and a second randomized list was presented. Subjects, again, typed the matching code for each letter in the list. After the second list was completed, subjects received feedback on the number of characters entered per minute and the percent correct. This sequence of the training screen presented for twenty seconds followed by a test trial consisting of two randomized lists was repeated until the subject could enter the twenty characters with only one error (95 percent correct). This procedure was followed for all three lessons. After the third lesson was passed, all three of the training screens were each presented for twenty seconds followed by the entire randomized character set. Subjects, again, were required to type the characters directly below the presented list. The number of trials to the 95 percent accuracy criterion and time spent on each of the four lessons was recorded. The training screens for the Alpha-dot and Microwriter keyboard groups are shown in Figures 10 and 11 respectively.

Lessons were presented in order of difficulty. The alphabetic lessons for the two groups were first ranked for ease of keypresses, creating an easy and difficult lesson. In Microwriter's lesson 2, for example, all the characters were constructed with a single press of one or two keys. The

O I D H E  
F T L A S

LESSON 1

1 2 3 4 5  
6 7 8 9 0

LESSON 2

P R B C G  
M W U N PERIOD

LESSON 3

Figure 10. Alpha-dot training screens.

• • • • • 1 .	• • • • • 2 •	• • • • • 3 •	• • • • • 4 •
	• • • • • 5 •	• • • • • 6 .	
• • • • • 7 .	• • • • • 8 .	• • • • • 9 .	• • • • • 0 .

LESSON 1

• • • • • E .	• • • • • O .	• • • • • S .	• • • • • U .
	• • • • • A .	• • • • • N .	
• • • • • T .	• • • • • H •	• • • • • I •	• • • • • C •

LESSON 2

• • • • • F •	• • • • • M .	• • • • • D •	• • • • • B .
	• • • • • G .	• • • • • P •	
• • • • • L •	• • • • • R •	• • • • • W •	• • • • • . .

LESSON 3

Figure 11. Microwriter training screens.

first lesson for the Alpha-dot keyboard presented the letters which are visually mapped exactly as they are printed and the ones that require identical keypresses for the top and the bottom of the character. The ordering of the three lessons by relative ease was confirmed by a pilot study for each group. Pretesting the Microwriter lessons showed that the lessons were in the correct order. Each lesson, after the first, required more time and number of trials to reach the 95 percent accuracy criterion than the previous one. Pretesting the Alpha-dot lessons showed that the easy alphabetic lesson was always easiest to learn, but the numbers and the difficult alphabetic characters were similar in their level of difficulty. An additional pilot study was conducted to determine the correct ordering for the Alpha-dot lessons.

Eight subjects were trained to operate the Alpha-dot keyboard with their left hand. Half the subjects were trained with the numbers lesson presented before the difficult letters and half the reverse. The results of an analysis of the number of trials to the 95 percent accuracy criterion indicated no significant differences between the two lessons,  $t(1,14)=0.37$ ,  $p>.05$ . The numbers lesson averaged 19.5 trials to criterion whereas the difficult letters lesson averaged 21.5 trials. An analysis of time to criterion also indicated no significant differences between the two lessons. Means of 18.1 minutes for the numbers lesson and 18.5 minutes for the difficult alphabetic lesson were observed,  $t(1,14)=0.04$ ,  $p>.05$ .

Text Entry. Following the successful completion of the entire character set, the following text entry test was presented.

- 1) A BEAR CAME OUT TO WATCH AS I MADE GROG.
- 2) THERE ARE EIGHT STEPS IN FRONT OF PAULA.
- 3) PEARL BUILT A MOUNTAIN OUT OF GREEN ICE.
- 4) SOME WHITE BIRDS DODGE THE BULLETS WELL.

The sentences were constructed to contain 40 characters each. Every alpha character in the set was presented at least three times. The code for the space bar was shown to the subject prior to typing the sentences. Each sentence was presented in the center of the screen and again, the subjects were required to match it character for character on a line directly below. Error correction was not allowed. Performance data were recorded indicating the subject's rate of entry and accuracy. This text entry test was used to establish a baseline rate of entry for each group.

Speed Building. Following text entry, subjects entered simulated cockpit data entry commands, such as UHF125 and LAT065 in order to increase their speed of data entry. All commands were comprised of three alpha characters followed by three random numeric characters. The three letter commands were taken from a subset of F-16 system acronyms (see Appendix B). Only commands which contained three unique characters were used. The stimuli for the speed building task were presented in the same manner as before, the

sequence to be entered appeared in the center of the screen and the subject entered the same item directly below it. Five lists of 40 randomized sequences were constructed so that each character was equally represented. Subjects entered the aircraft commands until they could be entered at a rate of 35 CPM averaged over five sequences while maintaining an accuracy of at least 90 percent correct. Subjects were given feedback after every five sequences by displaying rate of entry and percent correct as an average of the five previous sequences. Error scores and rate of entry were recorded for each sequence. The time and number of trials required to meet the 35 CPM criterion were recorded for each subject. One subject in the Microwriter group failed to reach the criterion rate in two hours and was replaced. After the criterion rate was reached, subjects again entered the four text sentences to test for equality of rate of entry for the two groups.

Artificial Speech Recognition. Subjects were trained in the recognition of artificial speech. A randomized list of all letters to be used in the secondary tasks were presented through headphones. The subjects were given a printed list of the letters in the same order to follow during training. Each letter was presented four times. Following this training, subjects were presented with a different randomized list of the same letters and were required to write the letter they heard on a form provided by the experimenter. Subjects were required to attain an accuracy of 95 percent or

better. Subjects were retrained on any letter not recognized three or more times out of the four presentations.

Secondary Tasks. In preparation for the dual task trials necessary to measure cognitive loading, subjects were given practice on two secondary tasks. Both secondary tasks were self-paced auditory classification tasks. In these tasks, the subjects heard single letters through earphones and were required to enter responses on a hand-held controller. The two tasks were the vertical line task and the letter-word task, developed by Colle and Ewry (1986). These two tasks were selected because one is primarily a spatial task (vertical line) and the other is primarily a verbal task (letter-word). Colle and Ewry (1986) have shown that these tasks are sensitive to manipulations of primary task demand. The operation of the Alpha-dot and Microwriter coding systems require a combination of spatial and verbal processing.

In the vertical line task the subjects were required to determine whether or not the letter they heard would have a vertical line in it if it was printed. The subject was instructed to consider the letters as being upper case and they were shown examples of each letter. The auditory stimuli for the vertical line task consisted of the letters B, T, H, K, L, N, P, and R for the positive set and A, C, O, Q, S, V, X, and Z for the negative set.

In the letter-word task the subjects were required to determine whether or not the letter they heard was also a noun, pronoun, or verb when pronounced. For example, the

letter "I" when pronounced produces the word "eye". The stimuli for the letter-word task consisted of the letters B, C, I, J, P, R, T, and U for the positive set. The negative set contained the letters F, G, H, K, L, N, V, and Z.

Lists of auditory stimuli were created containing 180 stimuli each. Each list consisted of six blocks of 30 stimuli. Within each block, half of the stimuli were positive (yes). Stimuli lists were randomized within each block with the restriction that repetitions of the same stimulus were not allowed in succession.

Dual-Task Practice. After practicing the secondary tasks alone, the subjects received practice performing the simulated cockpit data entry task and one of the secondary tasks at the same time. The dual task trials consisted of one of the self-paced auditory tasks and the data entry task presented at a rate of either 3 or 5 commands per minute. Each trial had a duration of 2 minutes. At the start of each trial, a ready message was displayed on the monitor. Subjects were instructed to try to keep up with the data entry task and to go as fast as they could on the self-paced auditory task while maintaining a low error rate, below 10 percent, on both tasks.

When the subject pressed the foot pedal to start a trial, the ready message was immediately replaced by the first aircraft command. The first auditory letter was presented simultaneously with the first keyboard command to be entered. For the remainder of the trial, the visual stimuli for the

data entry task occurred at the experimenter-determined rate specified for that trial. The concurrent auditory subsidiary task was subject-paced. A new auditory letter was presented as soon as the subject responded to the previous letter. At the end of the two minute test trial, the screen displayed a "ready" message.

Data entry task responses were scored on a character by character basis within each sequence. For each two-minute trial, the stimuli presented, the number of correct responses, and the number of errors including omissions were recorded. The performance measure for the auditory task was the number of correct classifications that were completed per minute. The number of errors was also recorded.

Subjects received a minimum of two trials of practice, one trial at the 3 commands per minute rate and one at the 5 commands per minute rate. If errors on either task exceeded 10 percent then the practice trial was repeated.

Dual-Task Testing. In each block of the dual task test trials, subjects received the four rates of the data entry task (2, 3, 4, or 5 commands per minute) while simultaneously performing one of the auditory secondary tasks. The highest rate, five commands per minute, required a typing rate of thirty characters per minute. In addition, one trial in each block consisted of the auditory task only. The first trial in each block was considered to be a warmup trial, presented at the 3 commands per minute rate and was not scored. Presentation of the rates was randomized within each block

with the restriction that the rates appeared equally often in each position across subjects. Each subject received four blocks of six trials. Within a trial, if the error rate for either task was over 10 percent, then the trial was repeated at the end of the block.

The stimulus lists for the data entry task consisted of 28 different simulated aircraft command sequences constructed so that individual alpha characters were presented equally often. The numeric component of each sequence was three random numbers. Each list contained the exact number of stimuli needed to present one block of trials. Four randomized lists were constructed so that a different list was presented for each block. Each of the four lists contained the same 28 three letter commands with a different random number sequence.

Following the completion of the dual task trials, subjects again typed the four text sentences, in order to determine if the two groups were still equated for rate of data entry.

A subject's overall schedule was as follows:

- Initial learning of coding strategy
- Text entry
- Speed building
- Text entry
- Secondary task training
- Dual task practice
- Dual task testing
- Text entry

## RESULTS

### Learning Trials

The learning trials were analyzed to determine if the two groups differed in the number of trials or in the total time needed to reach the 95 percent accuracy criterion. The number of trials refers to the total number of trials on all lessons including the final lesson which presented the entire character set. The time measure reflects the total time actually performing the learning task. Because time to complete a trial was under subject control, the two measures are not identical. The mean number of trials to criterion was 59.2 for the Alpha-dot group and 56.4 for the Microwriter group. These means were not significantly different,  $t(1,18)=0.30$ ,  $p>.05$ . The two groups also did not differ in the time required to reach the 95 percent accuracy criterion,  $t(1,18)=.02$ ,  $p>.05$ . The Alpha-dot group required 54.4 minutes and the Microwriter group required 54.6 minutes. Thus, the two coding strategies were learned at about the same rate. In both cases, it took less than one hour.

After the subjects attained the 95 percent accuracy criterion, they were given the first text entry test. The analysis of that test revealed that the Alphadot group was

typing at a significantly faster rate than was the Microwriter group,  $F(1,18)=5.63$ ,  $p<.05$ . The mean rate of text entry for the Alphadot and Microwriter groups were 34.65 and 26.87 characters per minute (CPM), respectively. There were no between group differences in accuracy of text entry,  $F(1,18)<1.0$ . The Alphadot group averaged 94.56 percent correct while the Microwriter group averaged 92.80 percent correct.

#### Speed Building

The speed building task trials were analyzed to determine if there were any differences between the two groups in the time or number of trials to reach the 35 CPM criterion. The number of trials to criterion refers to the total number of trials performed until five consecutive six character commands could be entered at an average rate of 35 CPM. Again, time is the actual time, in minutes, spent performing the task. Several subjects in each group were either already typing at 35 CPM or were very close to it. Others, in both groups, required considerably more practice. Due to the apparent floor effects, a non-parametric test was chosen for the analysis, the Wilcoxon Ranked Sum test for independent groups. Table 4 presents the ranks, means, and medians for each group. The results indicate that the Alpha-dot group reached the 35 CPM criterion rate in significantly less time than did the Microwriter group,  $W=132$ ,  $p<.05$ . The measure of the number of trials to the 35 CPM criterion yielded similar results, but the obtained W score was 131 which corresponds

to a p value of .052.

The objective of the speed building task was to equate the two groups for speed of data entry prior to the dual task testing for cognitive workload differences. The second text entry test immediately followed the speed building trials. The results of the second text test confirmed that the two groups attained equivalent performance levels. The Alpha-dot group attained an entry speed of 43.19 CPM and the Microwriter group reached 39.12 CPM.  $F(1,18)=1.24$ ,  $p>.05$ . The groups also did not differ significantly in accuracy, percent correct was 94.1 and 94.5, respectively, for the Alpha-dot and Microwriter groups.  $F(1,18)<1.0$ .

TABLE 4

Rank Orderd Data for Speed Building

	Time to Criterion (Rank)		Trials to Criterion (Rank)	
	Alpha-dot	Microwriter	Alpha-dot	Microwriter
	.75 (1.5)	.87 (4)	5 (3)	5 (3)
	.75 (1.5)	1.08 (6)	5 (3)	6 (6)
	.78 (3)	1.68 (9)	5 (3)	8 (9)
	.91 (5)	2.68 (10)	5 (3)	11 (10)
	1.33 (7)	5.75 (13)	7 (7.5)	25 (13)
	1.36 (8)	12.48 (16)	7 (7.5)	56 (16)
	3.48 (11)	13.82 (17)	16 (11)	59 (17)
	4.22 (12)	17.65 (18)	20 (12)	74 (18)
	10.83 (14)	21.39 (19)	45 (14)	78 (19)
	11.75 (15)	29.84 (20)	55 (15)	125 (20)
Mean	3.62	10.72	17.0	44.7
Median	1.34	9.12	7.0	40.5
Wilcoxon				
Ranked Sums	(78)	(132) *	(79)	(131)

\*  $p < .05$

### Dual-task

The dual-task trials were analyzed to determine if there were any differences between the two groups in the amount of additional cognitive work that could be accomplished while performing a data entry task at a given rate. The dependent variable was the number of correct classifications that were made on the auditory secondary task. A three factor ANOVA with repeated measures on two factors was used to analyze the data. The between subjects factor was keyboard group (Alpha-dot or Microwriter), and the two repeated measures factors were rate of data entry (0, 2, 3, 4, or 5 commands per minute), and secondary task (vertical line or letter-word).

The results indicated that there was a highly significant effect due to the rate of the data entry primary task,  $F(4,72)=462.3$ ,  $p<.001$ . The data are presented in Figure 12. Performance on the secondary tasks decreased from 58 to 24 correct responses per minute as the difficulty of the keyboard task progressed from two to five commands per minute. Thus, the auditory classification tasks that were used as secondary tasks, were sensitive to the varying demand of the different rates of data entry.

The main effect for keyboard group was not statistically significant,  $F(1,18)=1.99$ ,  $p>.05$ , indicating no overall differences in the amount of cognitive workload imposed by the two keyboards. However, there was a significant interaction between keyboard group and rate of data entry,  $F(4,72)=3.00$ ,  $p<.05$ . Performance on the secondary tasks were

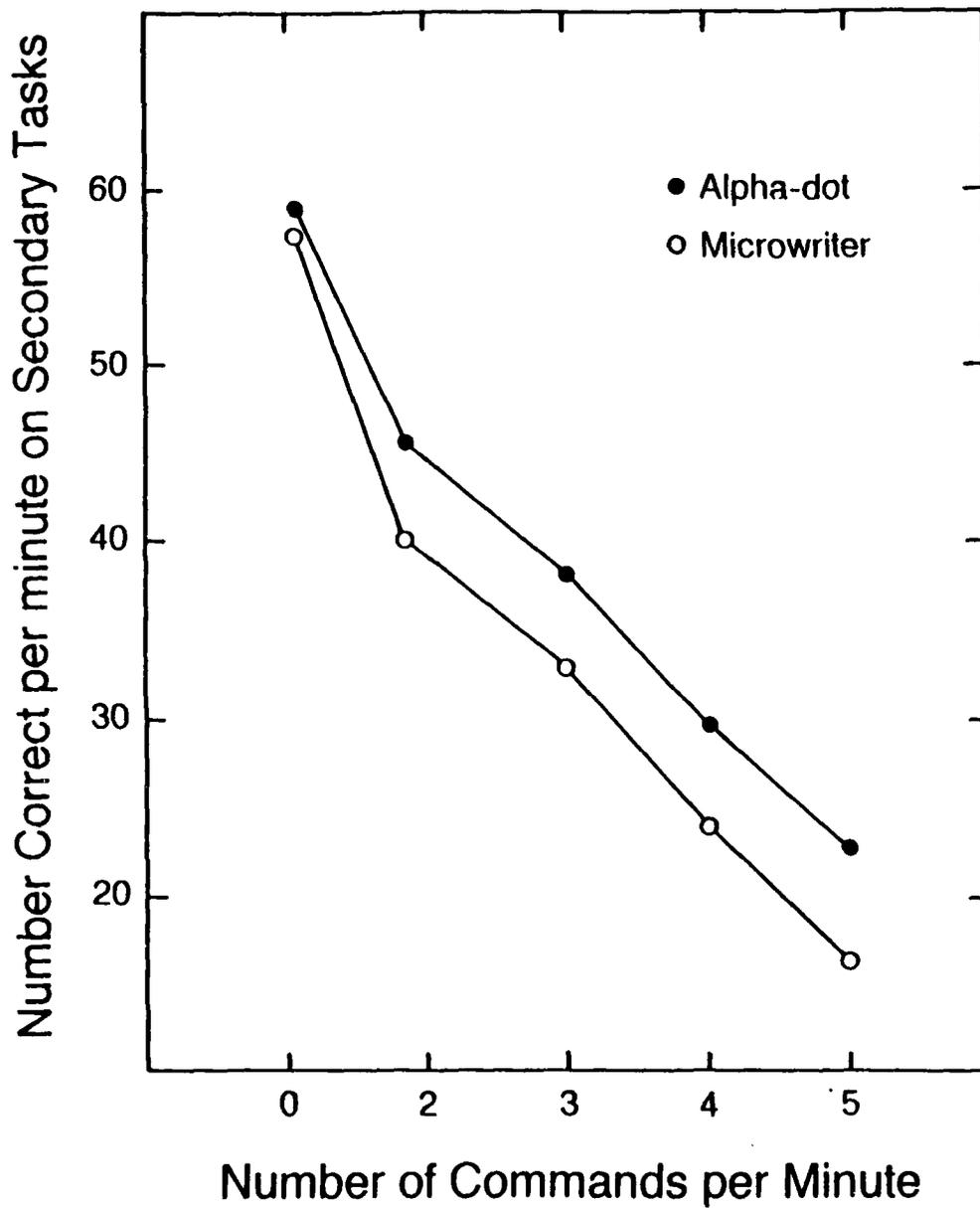


Figure 12. Number correct per minute on secondary tasks.

very similar when the keyboard task was not performed, but the Alpha-dot group was consistently better than the Microwriter group at all dual task levels. Additional analyses were performed to determine the source of the interaction.

The three factor ANOVA was repeated without the null rate level. This change had no effect on the main effects of the original analysis, but the keyboard group by rate interaction was no longer statistically significant,  $F(3,54)=1.82$ ,  $p>.05$ , suggesting that the significant interaction in the original analysis was due to the inclusion of the null rate condition. Newman-Keuls pairwise comparisons were performed at each rate of keyboard entry. None of these differences were statistically significant. To increase power, analyses of variance also were conducted on the data from each rate, including the factors of keyboard group and secondary task. The main effect of keyboard still was not statistically significant at any rate of the data entry task. The F-ratios (1,18) were: 0.02, 1.63, 1.24, 4.20, and 4.37, for the null rate condition and the 2, 3, 4, and 5 commands per minute conditions, respectively. These pairwise tests still have considerably less power than the keyboard by rate interaction in the main ANOVA because the keyboard main effects in these subanalyses are between groups comparisons, while the interaction effect is a repeated-measures comparison.

The main effect for secondary task was significant,  $F(1,18)=10.16$ ,  $p<.01$ , indicating that the subject's performance on the two tasks, the spatial intensive vertical

line task and the verbal intensive letter-word task, were different. On the average, subjects were able to classify more letters per minute on the vertical line task (36.8) than they could on the letter-word task (34.4). The mean numbers of correct responses for each task are presented in Table 5.

TABLE 5

Mean Number of Correct Responses per Minute on Secondary Tasks

Number of Commands per Minute						
Group	0	2	3	4	5	Mean
Vertical Line Task (Spatial)						
Alpha-dot	61.4	45.8	37.5	29.1	23.1	39.4
Microwriter	59.8	39.8	32.6	23.4	15.9	34.3
Mean	60.6	42.8	35.0	26.2	19.5	36.8
Letter-Word Task (Verbal)						
Alpha-dot	56.0	41.6	34.8	28.2	21.0	36.3
Microwriter	57.0	38.8	31.2	21.4	14.5	32.6
Mean	56.5	40.2	33.0	24.8	17.8	34.4

The interaction of secondary task and rate of data entry also was significant,  $F(4,72)=2.72$ ,  $p<.05$ . As before, the interaction disappeared when the null rate condition was excluded from the analysis,  $F(3,54)<1$ . The group by task and group by task by rate interactions were not significant,  $F(1,18)<1$  and  $F(4,72)=1.87$ ,  $p<.05$ , respectively. Thus, both secondary tasks were equally sensitive to the keyboard and rate effects under dual task conditions.

An error analysis was performed to determine if there were any differences between the two groups in the percentage of errors made on the data entry task during the dual task trials. Again, a non-parametric analysis (Wilcoxon Ranked Sums) was chosen because of the apparent floor effects. The results indicated that the two groups were not different in data entry accuracy,  $W=130$ ,  $p>.05$ . Mean error rates were 2.7 percent and 3.5 percent respectively, for the Alpha-dot and Microwriter groups. Table 6 presents the keyboard error data for each rate of data entry by secondary task.

An additional error analysis was performed to determine if the two groups differed in accuracy on the secondary tasks. Again, a Wilcoxon Ranked Sums test was used. The results indicated that there were no between group differences in the percentage of errors made on the two secondary tasks,  $W=93$ ,  $p>.05$ . The data are presented in Table 7.

TABLE 6

Mean Percent Error on Each Keyboard

Group	Number of Commands per Minute				Means
	2	3	4	5	
-----					
Vertical Line Task (Spatial)					
Alpha-dot	2.29	2.91	2.60	3.16	2.74
Microwriter	3.95	3.47	3.54	3.58	3.64
Means	3.12	3.19	3.07	3.37	3.19
-----					
Letter-Word Task (Verbal)					
Alpha-dot	1.87	3.74	2.08	3.25	2.74
Microwriter	4.79	2.77	3.01	4.08	3.66
Means	3.33	3.26	2.55	3.66	3.20
-----					

TABLE 7

Mean Percent Error on Secondary Tasks

Number of Commands per Minute						
Group	0	2	3	4	5	Mean
Vertical Line Task (Spatial)						
Alpha-dot	2.30	2.84	2.03	2.46	3.90	2.71
Microwriter	2.62	3.36	2.71	3.08	1.96	2.54
Letter-Word Task (Verbal)						
Alpha-dot	2.66	3.14	3.38	3.73	3.78	3.34
Microwriter	2.85	2.49	3.73	3.29	2.83	3.04

Following the completion of all the dual task trials, a third text entry test as given. The analysis of the third text entry test was performed to determine if the two keyboard groups were still equated for rate of data entry. The mean rates of data entry for the Alpha-dot and Microwriter groups were 47.1 and 39.7 CPM respectively,  $F(1,18)=3.75$ ,  $p>.05$ . The mean percent correct scores for the two groups were 94.3 and 95.6,  $F(1,18)=1.00$ ,  $p>.05$ . Thus, the two groups did not differ significantly in their data entry rate. However, the critical difference required for statistical significance was 7.9 CPM and the observed difference was 7.4 CPM.

#### Secondary Task Scaling

Capacity equivalence curves (CECs) were generated for the two secondary tasks following procedures outlined by Colle (1980) and Colle and Ewry (1986). Each data point was generated by recording the number of correct classifications per minute that was achieved when each secondary task was paired with the primary data entry task at a given rate. Thus, the performance on the letter-word task can be expressed in terms of the equivalent performance on the vertical line task at each rate. These relationships are depicted in capacity equivalence curves. Previous research with cognitive classification tasks has found linear CECs. Therefore, best-fitting straight lines relating performance on the two secondary tasks were obtained for each subject. A straight line function fit the data from all the subjects

very well. Of the twenty correlation coefficients that were obtained, the smallest was 0.93. To determine if each group had the same CEC function, the slopes and intercepts of the estimated functions were analyzed as dependent variables in a MANOVA. The results indicated that the functions describing the two groups were not significantly different,  $F(2,17) = 2.44$ ,  $p > .05$ . As Figure 13 shows, the data from both keyboard groups are well described by a single straight line. Thus, as Colle and Ewry (1986) have argued, all four tasks have additive effects on a single underlying capacity dimension.

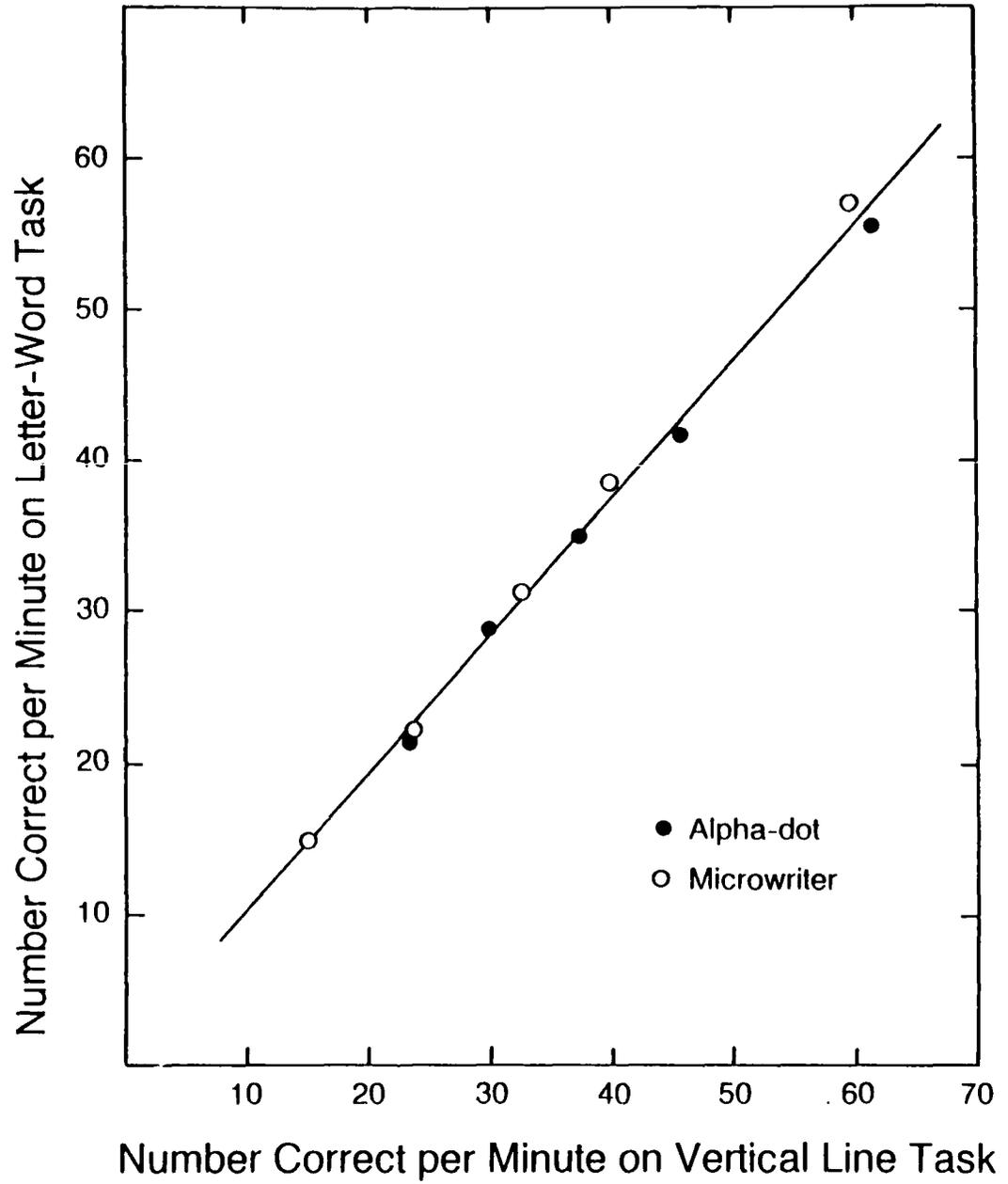


Figure 13. Secondary Task Capacity Equivalence Curves.

## DISCUSSION

Although no effort was made to optimize the subject's training, both of the coding strategies were learned very rapidly, 54.4 minutes for the Alpha-dot group and 54.6 minutes for the Microwriter group. A demonstration of rapid learning is important because one of the main objections to the use of any alternative keyboard is the amount of training required. If either one of these devices were implemented in an aircraft, the training required would not significantly impact the total training time a pilot receives. Comparing these learning times to those found by Baddeley and Longman (1978) for QWERTY keyboard training, of which the fastest was 34.9 hours, they are remarkably fast. Conrad and Longman's (1965) fastest reported learning time for the chord keyboard groups was approximately 31.5 hours. It must be noted, however, that the learning times reported in the present study were obtained from individual self-paced learning as opposed to group instruction, indicating that a different criterion was used for learning. The population sampled may also be different since this study only tested right-handed males.

The first text entry test showed that after minimal

accuracy training, the Alpha-dot group was typing at a significantly faster rate than the Microwriter group, 34.9 and 26.8 CPM, respectively. Remember that the Alpha-dot coding strategy requires two strokes per character as opposed to one stroke per character required by the Microwriter. Since there were no differences in accuracy, the differences in rate of data entry can not be explained by a speed-accuracy trade-off. The differences must originate in the coding differences of the two keyboards. Apparently, the Alpha-dot coding strategy is easier to use, at least at first, possibly due to the visually mapped characters. Again, these results can be compared with the results obtained by Baddeley and Longman (1978), which ranged from approximately 54 to 60 CPM after initial training on the QWERTY keyboard. Although neither the Microwriter nor the Alpha-dot groups reached the rates of data entry reported for QWERTY training, it must be noted that the QWERTY groups had a minimum of 34.9 hours of training whereas the two groups tested in the present study had approximately one hour. Conrad and Longman (1965) reported similar findings for QWERTY training. Their chord groups reached approximately 49 CPM after 31 hours of training.

The speed building routine was used to try to equate the two groups on data entry speed prior to the dual-task trials. Although the means for the two groups, 3.62 minutes and 10.72 minutes for the Alpha-dot and Microwriter respectively, were significantly different, a difference of seven minutes in reaching the speed criterion may not be practically

important. However, the 35 CPM criterion was an arbitrary point chosen because it could be reached quickly. If the pattern of the results continued, the use of a higher criterion rate may have shown larger differences between the two groups. Training to an operational rate of data entry, 50 to 80 CPM is needed to properly evaluate speed building.

The speed building routine was successful in equating the two groups for speed of data entry. The second text entry test indicated that the two groups were typing at rates that were approximately equal. The data entry rates were equated so that differences in dual-task performance could be attributed to cognitive differences rather than differences in keyboard data entry rate. The third, follow-up text entry test, was included to measure any data entry rate increases which may have occurred during the dual-task trials. Again, differences in data entry rates would make the interpretation of the dual-task trials difficult. The analysis of the third text test indicated that the two groups were still typing at rates that were not significantly different. The rates that were achieved, 47.1 and 39.8 CPM, again can be compared with the results obtained by Baddeley and Longman (1978), reported above. Although the rates reported here are still lower than those reported by Baddeley and Longman, the two groups in the present experiment, at this point, have a maximum of six hours of practice.

The results of the dual-task analysis indicated a significant interaction between rate and group and that the source of the interaction was the inclusion of the single

task performance point. This interaction indicates a difference between the two groups in the amount of the single to dual task decrement. The Microwriter group's performance on the secondary task decreased more than the Alpha-dot group's when the typing task was added. Again, these results were obtained in spite of the Alpha-dot keyboard's two stroke coding system. Entering one of the six character aircraft commands using the Alpha-dot system requires twelve keystrokes, whereas, with the Microwriter, nine strokes are required, including the mode change keystrokes. It is clear from these data that cognitive workload does not depend upon the rate of keystroke entry. Since both groups were typing at the same rate (CPM) and accuracy and performing equally well on the secondary task alone, it is concluded that there is less cognitive workload associated with the use of the Alpha-dot coding system (refer to page 32 for details of cognitive workload measurement). The amount of work accomplished on the secondary tasks is equivalent to the residual capacity of the operator while performing the primary task. Whether the differences are due to the advantages of Alpha-dot's visually mapped characters or the disadvantages of the mode changes required by the Microwriter cannot be determined from the results of this study.

Overall, the Alpha-dot coding system seems to be easier to use and no harder to learn than the Microwriter. Typing speed also increases faster with the Alpha-dot keyboard, at least early in training. Since this experiment only dealt

with low levels of training, it is impossible to predict outcomes of long-term training. Although code retention over time was not expressly examined in this study, the visually mapped characters, associated with the Alpha-dot keyboard, may make the character set easy to remember.

#### Cockpit Implementation

In order to implement a chord keyboard in an aircraft cockpit such as an F-16, the current data entry procedures must be translated into a command language to take advantage of the alphanumeric data entry capabilities of a chord keyboard. The current data entry device of an F-16, the integrated control panel (ICP) shown in Figure 14, uses a combination of dedicated pushbuttons, a multi-function ten key keypad, and several switches used to sequence through menus. This device is coupled with the data entry display (DED), also shown in Figure 14.

The five dedicated pushbuttons include two master mode buttons, A-A and A-G, which provide single switch selection of either air-to-air or air-to-ground fire control modes. The other four pushbuttons, COM 1, COM 2, IFF, and LIST, provide single switch override of the currently displayed data page. Functions, such as UHF and VHF radio control (COM 1 and COM 2) and identification, friend or foe (IFF) are accessed frequently. Selection of one of these three functions overrides the data currently displayed and replaces

DED

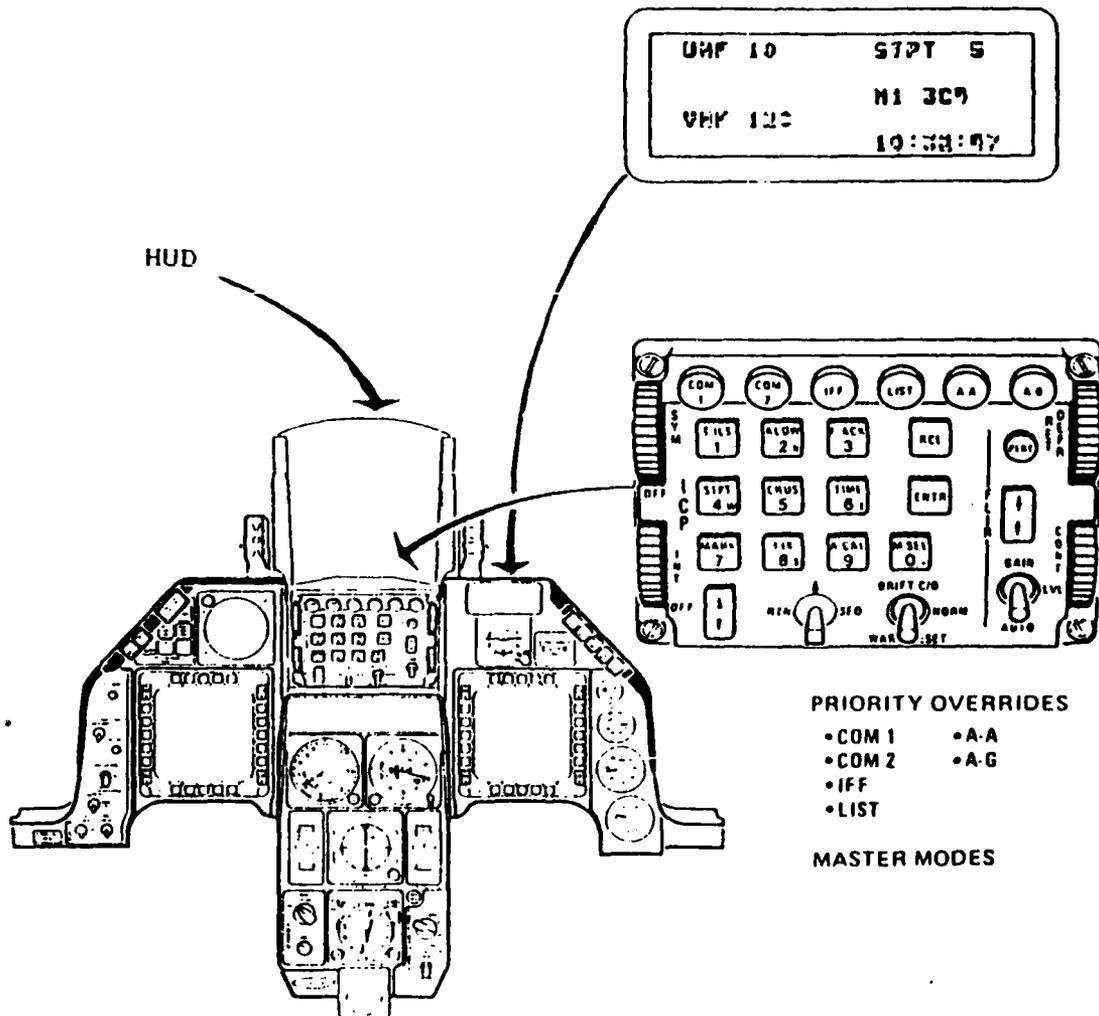


Figure 14. F-16 control panel.

it with the data corresponding to the function selected. A second press of the selected function returns the display to it's previous state. The LIST push-button operates the same way, but is associated with less frequently accessed data. Pressing the LIST button provides a menu of available functions.

The priority function pushbuttons, the ten key keypad, can be used only when the communication, navigation and identification (CNI) page is displayed. When one of the buttons is pressed, the function page is displayed on the DED. The sequence toggle switch is then used to move a cursor on the display. When the cursor is on an item where data entry is allowed, the ten keys can then be used to enter numerical data.

The data entry system is basically organized as a hierarchical menu. The selection of a function displays a menu of further choices. Some of those choices may display another menu until a point is reached where numerical data entry is allowed.

The use of alpha-numeric commands will allow direct access to any level of the hierarchy by calling functions by name rather than sequencing through a menu. Construction of a command language will be aided by the fact that all functions and terminology already have accepted abbreviations (see Appendix B). The head-up data entry capability gained from the use of a chord keyboard will require data to be displayed on the head-up display (HUD), shown in Figure 14.

This requirement will not be difficult to implement since the data displayed on the DED is also displayed on the HUD.

A chord keyboard located on or near the throttle would provide easy access to all data entry functions. It would not only provide a means of head-up data entry, but would also eliminate the need to reach forward to enter data, a task complicated by the forces generated by acceleration and high speed maneuvers. Although the abbreviations used currently will help in the construction of a command language, quick access to frequently used or critical functions will be needed. These critical functions will have to be accessed with shorter commands.

The results of this study indicate that the Alpha-dot system would be chosen, over the Microwriter, for a cockpit data entry device. Although the Alpha-dot keyboard appears to be easier to use than the Microwriter, this does not necessarily mean that it is the optimum choice for cockpit data entry. Further work needs to be done to improve, if not optimize, the keyboard. Some of the Alpha-dot codes did not correspond to the letter's shape as closely as would be desired. Adding a numeric mode switch would enlarge the possible character set size and possibly result in more accurate mapping. However, the effects of mode switching itself must first be determined. Overcoming these problems may result in a keyboard that is easier to learn and use than either of the two tested here.

### Other Potential Uses of Chord Keyboards

Although the focus of the research reported in this study was the use of chord keyboards in aircraft cockpits, these devices may have other potential uses. Kirshenbaum, Friedman, and Melnik (1986) reported studies of the use of chord keyboards by the handicapped. Persons with limited motor functions may well be able to operate chord devices easier than they could type on a standard keyboard. Chord keyboards could also be used in space limited workstations and on tasks requiring the use of one hand while simultaneously processing information.

APPENDIX A

## APPENDIX A

### Instructions to subjects

In this experiment, you are going to learn how to type on a one-handed chord keyboard. This chord keyboard is a device that has only six keys, one for each finger and two operated by the thumb. You will be taught how to operate it by a computer-aided instruction program. Before we begin, I'd like to give you some practice in the recognition of artificial speech. Follow along this list as the computer pronounces each letter. (run practice program) Now I'd like you to write down the letters you hear on this form. (run test program)

Take a moment now to acquaint yourself with the keyboard. Notice how it fits your left hand. Each finger has its own key so that there is no movement between keys. Characters are produced by single and multiple keypresses. This keyboard is different in several ways to ones that you are probably familiar with. First, the characters are printed upon the release of the keys rather than when they are pressed. Second, you will notice that the keys are not marked. This is because each key will be used to make

several different characters. The instruction program will step you through four lessons. The first three will show you how to make ten characters each. The patterns you will see will look like this (show card). The dots correspond to the keys. The large dots indicate what keys to press to make the indicated character.

A training screen, showing ten characters and how to produce them, will be on the screen for twenty seconds. During that time, I would like you to practice making the characters. At the end of the twenty seconds you will see a "READY" message. At this point, you should stop practicing and wait for the line of characters to appear in the center of the screen. When you see the line of characters, your task is to enter the exact same line. There will be a cursor underneath the first character in the line to indicate your position. Try to remember as many of the codes as you can, but I do not expect you to know them all at first. If you do not remember a code, just guess. After you finish the line, another will appear. Do the same thing with this second line. When you finish the second line you will see a screen that will tell you how you did. It will give you percent correct scores and characters per minute scores. Next, the screen will go back to the original training screen. You will continue this until you have learned all the characters in the lesson (95% correct). You will then proceed to the next lesson. The fourth lesson is a combination of the first three. To start each lesson, press the foot pedal by your left foot. When you have completed all four lessons, stop

and take a short break. Are there any questions before you start? (run training program)

Now I'd like you to enter some text. There will be four sentences and I would like you to enter them as quickly and as accurately as you can. The space is made by pressing this key. (run text test)

Now that you have learned all the characters, you can work on your speed. This program will present you with simulated aircraft commands such as LAT124. These commands will appear in the center of the screen one at a time. Enter them just as you did before. You will receive feedback on speed, in CPM and accuracy, in percent correct, after every five commands. You will work on this until you can enter the commands at 35 CPM with 90% accuracy. (run speed building program)

Now I'd like you to type the four text sentences again. Remember to type as fast as you can while minimizing your errors. (run text test)

Ok, now that you are familiar with the keyboard, I'd like to give you some practice on the two auditory tasks to be used in the next portion of the experiment. The first one is the vertical line task. Your task is to listen to the letters presented over the headphones and to determine if the letter you hear would have a vertical line in it if it were printed as a capital letter. This card illustrates the task. If you hear the letters B, T, H, K, L, N, P, or R, then you respond "yes, it does have a vertical line in it" by pressing the forefinger button on the hand controller. If it does not

have a vertical line in it, like A, C, O, Q, S, V, X, and Z, then respond "no" by pressing the thumb button. These sixteen letters are the only ones you will hear in this task. To start the task, press the foot pedal by your left foot. As soon as you press it you will hear the first letter. You will hear the next letter as soon as you respond to the first. So, in this way you control the rate of the task. I'd like you to go as fast as you can while keeping your errors less than 10%. Are there any questions? (run vertical line program twice)

The other task is called the letter-word task. In this task, you will, again, hear letters presented over the headphones, and this time you need to decide if the letter you hear is also a noun, pronoun, or verb when pronounced, as shown on this card. (show card) If you hear the letter B, C, I, J, P, R, T, or U, then respond "yes" by pressing the forefinger button. If it is not a word, F, G, H, K, L, N, V, or, Z, then press the thumb button. Again, go as fast as you can while maintaining a low error rate, less than 10%. Questions? (run letter-word program twice)

Now you are going to practice one of the auditory tasks, and at the same time, enter the aircraft commands on the keyboard. This time, though, there will be a deadline for the typing task. Deadlines will be either 20 or 12 seconds to enter each command. Enter each command as fast as you can while maintaining a low error rate, less than 10%. The auditory tasks will again be self paced, you will control the rate of these tasks. Your primary task is the keyboard task.

If you are having difficulty keeping up with the typing task, then slow down on the auditory task. Remember, try to minimize errors on both tasks. Any time errors are over 10% the trial will be repeated. Try to keep up with the keyboard task and go as fast as you can on the auditory task. Start the trial by pressing the foot pedal. As soon as you press the pedal, the first aircraft command will appear in the center of the screen and, at the same time, the first auditory letter will be presented. Questions? (run dual-task practice program)

The dual-task test will be like the practice, except several different rates will be added. Deadlines will be 30, 20, 15, or 12 seconds to enter each command. One trial in each group will be the auditory task only. Remember to try to keep errors less than 10%. Questions? (run dual-task test program)

Finally, I'd like you to enter the four text sentences again. Enter them as fast as you can while minimizing your errors. (run text entry test)

APPENDIX B

## APPENDIX B

### F-16 System Acronyms used in the Speed Building and Dual-task Trials

ADI	attitude direction indicator
AGR	air-to-ground ranging
ALT	altitude
AUD	audio
BAL	ballistics
BCN	beacon
BRG	bearing
CNI	communication, navigation, identification
DOI	display of interest
ECM	electronic countermeasures
EMC	electro-magnetic countermeasures
EMD	energy management display
ETA	estimated time of arrival
FCR	fire control radar
GMT	ground moving target
GRD	guard
HDG	heading
HOM	home
HSI	horizontal situation indicator
HUD	head-up display

ICP	integrated control panel
ILS	instrument landing system
LAT	latitude
LNG	longitude
LRU	line replaceable unit
MFD	multi-function display
OPF	operational flight program
OSB	option select button
PWR	power
RBM	real beam map
REL	release
REP	release pulse
RHP	right hand point
TBD	to be done
TOF	time-of-flight
TWS	track-while-scan
UFC	up-front control
UHF	ultra high frequency
ULS	up-look search
WPN	weapon

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