Numeric Keyboard Layouts: An Ergonomic Approach

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NUMERIC KEYBOARD LAYOUTS:
AN ERGONOMIC APPROACH

by
Tricia S. Lowe

A Thesis Submitted to the
Graduate Studies Office
in Partial Fulfillment of the Requirements for the Degree of
Master of Aeronautical Science

Embry-Riddle Aeronautical University
Daytona Beach, Florida
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by

Tricia S. Lowe

This thesis was prepared under the direction of the candidate's thesis committee chairman, Daniel J. Garland, Ph.D., Department of Aeronautical Science, and has been approved by the members of her thesis committee. It was submitted to the Department of Aeronautical Science and was accepted in partial fulfillment of the requirements for the degree of Master of Aeronautical Science.

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ABSTRACT

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This study investigated the most effective method of numeric data entry, by means of a numeric keypad. The methods of numeric data entry were (a) two keypads with different numerical configurations, (b) two keypads with identical numerical configurations, and (c) one keypad with only a single numerical configuration. The two configurations utilized were the telephone and the calculator. An experimental design, with focus on the post-test only control group, was utilized. Sixty randomly selected students from the population attending Embry-Riddle Aeronautical University were assigned to five experimental groups.

The results indicated no significant differences: (a) for the number of errors and the time required for entry, between the single and double numerical configurations, and (b) between the single numerical configurations. However, even though there was no statistical support, the double configuration of the calculator and telephone had the highest occurrence of errors, and there was some evidence that the single configuration of the calculator was most efficient of all the tested keypads.
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INTRODUCTION

The numeric keypad is a fundamental and increasingly popular item of human interaction with computer systems. Keying numeric data into an operating system is a highly repetitive task, which requires an efficient layout. The operating system may involve a full-time operator performing just a few key strokes to 100,000 keystrokes on a daily basis.

Utilization of the two common numerical layouts, the telephone and the calculator, on an operating panel can possibly lead to an increase in operators' confusion and errors, while simultaneously diminishing their speed. For example, both numerical layouts co-exist on one panel, each with different functions, in the Federal Aviation Administration (FAA) Air Traffic Control Systems Command Center.

Due to the increasing usage of multiple function keypads, and with only a few guides being available to assist designers as to which arrangement is the best for numeric entry in different operational settings, additional research was warranted. Therefore the methods of numeric data entry that were studied are: (a) two keypads, with different numerical configurations incorporated with two functions on one keypad and one function on the other keypad, (b) two keypads with identical numerical configurations, incorporated with two functions on one keypad and one function on the other keypad (c)
one keypad with only a single numerical configuration, incorporated with the three functions. The two layouts utilized in the experiment were the telephone and the calculator.

**Statement of the Problem**

This study investigated the effectiveness of two numerical configurations in terms of their influence on operator efficiency and productivity (i.e. speed and accuracy). Of special concern was the assessment of the ergonomic effects of using two different numerical configurations on one operating panel.

**Review of Related Literature**

Many methods of numeric data entry have been studied. Minor and Ravesman (1962) compared four numeric entry devices: a ten-key keypad with full visual feedback, levers, a matrix keyboard, and rotary knobs. Even though inexperienced production employees were used as subjects, it was found that fewest errors were made on the ten-key keypad. Performance on the ten-key keypad was faster than the levers and knobs for data entry and equal to that of the matrix keyboard. The ten-key keypad was also the most preferred.

Deininger (1960a) conducted an experiment utilizing 16 arrangements of push button telephones at the Bell Telephone Laboratories. These 16 arrangements were selected on the basis of surveys, previous studies, engineering analyses, and population stereotypes. Crosses, triangles, boxes, squares and circles were among the arrangements
studies, including the $3 \times 3 + 1$ matrix. Significant differences were found in the keying times and errors for these numeric configuration comparisons, and the most preferred arrangements tended to be the best in terms of performance. The 16 arrangements that were used as the initial groups were reduced to the four fastest and most preferred arrangements. The four superior arrangements and the one similar to the standard rotary dial were then compared. No significant differences were detected among the keying times and error rates for the five arrangements.

In the United States, no single industry or military standard for numeric keypads or basic key characteristics (size, operating force, or displacement) has been formally established (Alden, Daniels, & Kanarick, 1972). The lack of standards for the layout of numeric keyboards has led to the use of several arrangements. The most common of these arrangements are the telephone configuration (1, 2, 3 across the top) and the calculator configuration (7, 8, 9 across the top) in a $3 \times 3 + 1$ matrix.

Lutz and Chapanis (1955) tested six different key configurations to determine where people expected each number to appear on ten-button keysets, because learning is more rapid and errors are fewer for tasks in which the stimuli and required responses are in an expected relation. The findings concluded that people placed numbers on keys in the same order as they read text (from left to right and from top to bottom), regardless of the configuration. Only eight percent indicated that the key for number 1 should be at the bottom left hand corner, as in the calculator format.

Conrad (1966) conducted a $3 \times 3 + 1$ matrix study of a high-compatible keypad (telephone configuration) and a low-compatible keypad (5 2 4, 9 0 7, 3 6 1, 8
respectively). When utilizing a numerical data-entry keyboard, if the key layout has a poor/low level of Stimulus-Response (S-R) compatibility with normal expectations of the location of the digits, subjects required more time to locate each key. This occurs because there is an association with an increase in recall errors for material held in memory store during keying. Therefore proving that entry (keying) rate will be lower than that of a keyboard with a high level of S-R compatibility. One should observe that the telephone configuration is currently being utilized on new aircraft such as the B-777 by Boeing Company and the A-3XX by Airbus Industrie (Lambert, 1993). National Aeronautics and Space Administration (NASA) also utilizes the telephone layout aboard all their space shuttles (Yenne, 1989).

Later studies have compared performance between the telephone layout and the calculator layout in a 3×3+1 matrix. Conrad and Hull (1968) found, in entering numeric codes, the telephone layout was exceptional in both speed and accuracy, and alternation between layouts degrades performance. Klemmer (1971) concluded that the telephone matrix is generally best, particularly for low-skilled operators. Shneiderman (1987) found only a slight advantage for the telephone layout. The telephone layout has been accepted internationally as the standard for push-button telephones, and computer input devices are now serving as input devices for telecommunications. This implies that the telephone layout appears to be the layout of choice for many applications (Salvendy, 1987). Anyone who has tried to dial a telephone number on a non-telephone keypad, will appreciate the inclusion of a telephone layout for this and similar functions (Helander, 1990).
On the contrary, in a study for the Federal Aviation Agency, Paul, Sarlanis, and Buckley (1965) tested Air Traffic Controllers and found that neither the telephone, nor the calculator design, were superior. In a study conducted by Stealey (1985), a well equipped U. S. Army command post may have more than three keypads, built by different manufacturers, varying from slightly to radically different keyboards. Results indicated that there is no difference between the telephone and the calculator layout. This is due to the upcoming generation being familiar with both types of arrangements and able to operate either one reasonably well. It was stressed that consistency in arrangement of a numeric keypad should be strictly adhered to. Carey (1988) and Seibel (1972) also supported the fact that there are no differences in performance between the two numerical layouts. Carey concluded that consistency of layout and function designation is much more important than the numerical layout.

A possible reason for these conflicting results between the calculator and telephone configurations may have been caused by the inconsistency of various experiments’ instructions. According to Howell and Kreidler (1963), the instructions used in many psychological experiments are ambiguous or contradicting. Subjects are frequently instructed to maximize two or more quantities, each of which requires a different and incompatible way of responding. Furthermore, the instructions that are commonly used emphasize both the speed and accuracy of responding, with their goals being antagonistic.

To determine how contradictory instructions can influence performance on a typical information-processing task, an experiment was performed utilizing four sets of
instructions. The first instruction was of a contradicting nature, with equal emphasis being placed on accuracy and speed. The latter three instructions were non-contradicting in nature: (a) speed exclusively, (b) accuracy exclusively, and (c) to convey information at the fastest possible rate. Results from this experiment indicated:

1. There was little difference between contradictory and non-contradictory instructions, with respect to speed.

2. With respect to accuracy, there was a large difference between the 'speed exclusively' instructions and all the other instructions. The 'speed exclusively' instructions had a lower accuracy rate.

With concern to individual key design standards, Pollack and Gilder (1963), reviewed manual computer input devices and summarized the characteristics of commercially available keyboards. According to their report, considerable variation existed in key shape (square, round, rectangular), operating force (ranging from 2 to 8 ounces (oz), or 57 to 227 grams (g)), and displacement (0.067 to 0.625 inches (in), or 0.71 to 1.59 centimeter (cm)). Harkins (1965) also acknowledged the existence of a wide variety of key configurations. Harkins believes this variety is due to design conventions rather than empirical data, and notes that keys of 0.50 in (1.27 cm) in width or diameter are found on most typewriters and ten-key keyboards. The typical spacing between key centers on these keyboards is 0.75 in (1.81 cm). Some ten-key adding machines have the same key size, but reduce the distance between key centers to 0.69 in (1.75 cm).

Dreyfuss (1959) recommended, as a human factors standard, that the operating force for keys in a keyset ranged between 4.1 and 11 oz (117 and 312 g) with 0.187 in
(0.47 cm) displacement. In addition, Dreyfuss recommended a maximum key size of 0.50 in (1.27 cm) width and 0.438 in (1.11 cm) in length. The United States military standard MIL-STD-803 A-1 (1964) lists 32 oz (908 g) as the optimum operating force for an individual push-button, a value too high for effective keyboard operation. In the face of these rather broad recommendations, keyboard manufacturers have generally selected their own design criteria for individual keys (Alden et al., 1972). It should be observed that regardless of key design, most commercially available keyboards utilize the calculator format, such as the Human Applications Standard Computer Interface keyboard (Rutkowski, 1982).

Deininger (1960b) conducted an inclusive research experiment, utilizing 10-key numeric keypads of two different configurations, on the effects of four variables of key design: size, force, displacement, and feedback. The subjects' task was to key in telephone numbers with different ten-key push-button sets. Deininger found that the largest difference in performance resulted from varying the button-top size. Increasing the diameter size of a square button from 0.375 to 0.500 in (0.95 to 1.74 cm) reduced keying times from 6.35 to 5.83 seconds, while it reduced errors from 7.3 to 1.3 percent. Further, Deininger found that varying the force from 3.5 to 14.1 oz., (100 to 400 g.) or varying the maximum displacement from 0.03 to 0.19 in (0.08 to 0.48 cm.) produced insignificant differences in subject performance. Subjects' reports indicated a preference for the light-touch keys, and a definite dislike for keys requiring greater displacement.

Kinkead and Gonzalez (1969), using eight experienced typists as subjects, evaluated the influences on key force and displacement of key-pressing performance.
Results indicated that performance was best when both force and displacement were at relatively low levels, which are 0.9 to 5.3 oz. (25.5 to 150.3 g.) and 0.05 to 0.25 in. (0.13 to 0.64 cm.) respectively.

Klemmer (1971) evaluated keyboard data entry with emphasis on key design standards. It was found that the best arrangement of the numeric keypad is the $3\times3+1$ matrix in the telephone configuration. For keypads that were utilized frequently, it is necessary for the keypad to be configured with these specifications: short-stroke, light-touch action, with some separation between keys. In general, the results of the few studies of individual key force and displacement are that these parameters (within certain limits) have little effect on the keying performance of experienced operators (Alden et al., 1972).

In all key-pressing tasks, there is kinesthetic feedback from depressing the key, auditory feedback from the key depression and/or activation of the print mechanism, and visual feedback from the keyboard and output display. Deininger (1960b) found no statistical differences in speed and error performances when auditory and kinesthetic feedback was added. Diehl and Seibel (1962), utilizing four types of feedback conditions (normal, visual masking, auditory masking, and both visual and auditory masking), found no significant performance differences. Kinkead and Gonzalez (1969) found that the absence of kinesthetic snap-action feedback did not affect typing speed, yet operators made a significantly greater number of errors. Brunner and Richardson (1984) found that lower error rates and greater throughput speed were achieved with the elastomer key-
action keyboard than with the snap-action keyboard. The review of literature indicates that feedback is not necessary for efficient keying performance.

Pollard and Cooper (1979) conducted research for the United States Postal Service. This experiment assessed the effects on key performance utilizing the conventional keyphone (keys protruding from the base), the capacitive keyphone (keys recessed into the base), and the membrane keyphone (keys on the surface of base). There was a significant difference in mean keying time per sequence for all three groups; capacitive keyphone (7.43 seconds), conventional keyphone (7.089 seconds), and membrane keyphone (6.949). Error rates were significantly higher with the capacitive keyphone (10.99 percent) and membrane keyphone (11.55) as compared to the conventional keyphone (3.17 percent). Capacitive keyphones proved to be very sensitive; the finger only needed to be near the key for it to be actuated, thus giving operators no chance to change the position of their finger. Some females with long finger nails complained that the recessed keys of the finger plate made the capacitive keyphone difficult to use and this could possibly be a problem during utilization. Subjects preferred the conventional keyphone, rather than the capacitive and membrane keyphone by 42 to 32 and 31 respectively, concluding no significant difference.

Summarizing, numerous studies have been conducted on numeric data entry; such as the types of arrangements (crosses, triangles, boxes, squares, and circles), types of hardware (conventional, capacitive and membrane), and configurations within one arrangement (telephone and calculator). And still there are conflicting views as to which is the more efficient method of numeric data entry. Also, there is no formally established
industry standard for the production of numeric keypads within the United States. Due to the increasing usage of multiple function keypads, and with only a few guides being available to assist designers as to which arrangement is the best for numeric entry (Hagelbarger and Thompson, 1983), additional research is necessary.

**Statement of the Hypothesis**

Operating panels containing two different sets of numerical configurations require the user to remember and apply more information than required by a single configuration; therefore, it is hypothesized that one single keypad configuration of either the telephone or the calculator, should lead to a high level of efficiency, in terms of the operators’ accuracy and speed.
METHOD

Subjects

The participants for this study were student volunteers from the undergraduate and graduate population attending Embry-Riddle Aeronautical University (E-RAU) in Daytona Beach, Florida. A total of 60 subjects participated in the study. The students had no extensive knowledge or experience concerning numeric data input on either of the two keypad configurations.

Instruments

This study utilized several major instruments. The primary instruments were two separate numerical keypads. The spatial arrangement of digit keys for the keypads were comprised of three rows, each with three keys, with an elongated zero key found across the bottom, center location; a 3×3+1 matrix. One keypad was configured as a telephone and the other as a calculator.

In addition to the 3×3+1 arrangement, there were three function keys, representing three types of input data: D (air traffic control data), IN (internal telephone number), and EX (external telephone number). The function keys were located above the numeric keys. The single numeric keypads used all three function keys. When utilizing two
keypads, the D and IN function keys were placed on the first keypad, and the EX function key was placed on the second keypad. The numerical keypad configurations are illustrated in Appendix A.

The keypad's specifications consisted of the conventional short-stroke, light-touch action with some separation between the keys. Each keypad's output was directed into a computer, which enabled immediate feedback of the time and accuracy of data input. The feedback was displayed on the computer monitor and a hard copy was also printed for future reference.

A stimulus list of numbers, compiled from Arkin, Herbert, Colton, and Raymond "Table of Random Numbers", in the Tables for Statisticians (1963), was also utilized. There were 120 sequences of numbers on the list, each sequence consisting of random digits of varied string length. Each sequence was specified as one of the three functions and was displayed to the participant, one at a time, on a computer monitor.

**Design**

The researcher utilized the experimental research method as outlined in the textbook Educational Research, by Gay (1992). The experimental method of research is the only method that can test hypotheses concerning cause and effect relationships, and it is the most valid approach to problem solving. The researcher has direct manipulation of at least one independent variable, which was required for this study.
An experimental design, with focus on the post-test only control group, was utilized. This design was selected because there was no pre-test warranted. This issue was important because the experimental groups had no knowledge related to the dependent variables. There was one independent variable, incorporated with five levels, which was the manipulation of the type of numeric keypad that was utilized. There were two dependent variables: the measure of accuracy and the time of each experimental group.

A diagram for the True Experimental Design is displayed below. This diagram represents the subjects being assigned to one of the five groups. Each group was then presented with one of the five experimental treatments on two different occasions, and was tested on both occasions.

\[
\begin{align*}
\text{A} & \quad \text{X}_{E1} \quad \text{X}_{E1} \quad \text{O} \\
\text{A} & \quad \text{X}_{E2} \quad \text{X}_{E2} \quad \text{O} \\
\text{A} & \quad \text{X}_{E3} \quad \text{X}_{E3} \quad \text{O} \\
\text{A} & \quad \text{X}_{E4} \quad \text{X}_{E4} \quad \text{O} \\
\text{A} & \quad \text{X}_{E5} \quad \text{X}_{E5} \quad \text{O}
\end{align*}
\]

\textbf{Note:} Each line represents a group.

A: Assignment of participants to groups.
$X_{E1}$, $X_{E2}$, $X_{E3}$, $X_{E4}$, and $X_{E5}$: Experimental treatments.
O: Post-Test.

\textbf{Procedure}

The primary instruments utilized in this study were two separate numerical keypads; one configured as the telephone and the other as the calculator. Each keypad's
output was directed to a computer. In addition to the keypads were three function keys, representing three types of functions: D (air traffic control data), IN (internal telephone call), and EX (external telephone call). Experimental stimuli were contained in a numeric list of numbers consisting of 120 sequences, compiled from Arkin et al. "Table of Random Numbers", from the textbook *Tables for Statistics* (1963). Each sequence contained in the numeric list was specified as one of the three functions and displayed to the participant on a computer monitor.

The participants were assigned to one of five the groups, based upon the particular day's configuration setup: (a) group 'C' worked exclusively with one keypad of the calculator configuration, (b) group 'T' worked exclusively with one keypad of the telephone configuration, (c) group 'CC' alternated between two keypads of the calculator configuration, (d) group 'TT' alternated between two keypads of the telephone configuration, and (e) group 'CT' alternated between two keypads of the calculator and the telephone configuration. There was no control group due to irrelevancy.

Each participant performed their given task individually in a quiet room. Before beginning their encoding task, the participant listened to a pre-recorded audio cassette tape and also read along on the computer monitor, the necessary instructions to perform the specific task. This recording also include a scenario designed to obtain the participant's attention and to provide an incentive to achieve their maximum capabilities. The instructions explained the details of the experiment as follows: (a) the scenario, (b) the type of task to be performed, (c) procedures to accomplish the task, and (d) the procedure to follow if a mistake was made. After the instructions were given, questions
concerning the procedure were answered and the requirements were clarified as necessary.

The 120 sequences of numbers along with their corresponding function were displayed to the participant, one at a time, on a computer monitor. An example of each type of function statement, with a sequence of numbers are:

Input the air traffic data: 546 79
Dial this internal number: 8679
Dial this external number: (809) 456-2356

The sequences were entered into the appropriate keypad, depending on its function. To input the sequence of numbers, the participant depressed the corresponding function key first, then entered the sequence of numbers; accuracy and speed being of equal importance. The ‘Enter’ key was depressed after each sequence of numbers. If the participants thought that they made an error of any kind, they were instructed not to correct the error, but to continue with the inputting process.

After 60 sequences were entered, a brief rest period was given of approximately three to five minutes. The participant then resumed entering the remainder of the sequences. The participants were tested with this procedure for two days, within a one week period. Each participant was required to complete a computer based questionnaire to evaluate user satisfaction of the numerical configurations, after he/she had completed the encoding task on the second day.

All of the subjects data were collected by the computer. The results from this experiment were then utilized to test the research hypothesis, which states: Operating
panels containing two different sets of numerical configurations require the user to remember and apply more information than required by a single configuration; therefore, it is hypothesized that one single keypad configuration of either the telephone or the calculator, should lead to a high level of efficiency, in terms of the operators’ accuracy and speed.
ANALYSIS

Productivity performance on five groups of 60 students (12 students in each group) were analyzed, for a total of four sessions, at a confidence interval of 0.05. Each group performed on one of the five keypad configurations; C, T, CC, TT, and CT. Productivity performance for each student was measured for Reaction Time (RT)--the time it takes from when the message appears on the computer monitor, to when the participant depresses the first function key; Mean Time Per Keystroke (MTK)--the (length of sequence/time) to input each sequence; Total Time (TT)--the total time to input each 60 sequence set; and Errors--the number of errors that occurred during each 60 sequence set. Further analyses was conducted on each type of function [data, internal number and external number] in relation to RT, MTK and TT.

It was hypothesized that there would be (a) a significant difference between the number of errors and the time required for entry (this includes RT, MTK, and TT), for the single numerical configurations and the double numerical configurations, with either of the single numerical configurations being more efficient (fast and accurate), and (b) no significant differences between the single numerical configurations.

Reaction Time - Group Main Effect

For productivity performance on Reaction Time, the means were found to be 1.475, 1.527, 1.612, 1.551, and 1.608 for the groups C, T, CC, TT, and CT respectively, regardless of the trial number. A graph of the group means is displayed in Figure 1. Due
to Hypothesis A, which states that there will be a significant difference between the number of errors and the time required for entry, for the single numerical configurations and the double numerical configurations, six planned comparisons were conducted. These comparisons were C and CC, C and TT, C and CT, T and CC, T and TT, and T and CT. Hypothesis B stated that there would be no significant differences between the single numerical configurations, therefore one planned comparison was conducted between C and T. The results concluded no significant differences between any of the group comparisons.

Due to the result of the planned comparisons, Hypothesis A proved to be incorrect; there was no significant difference for RT for the single numerical configurations and the double numerical configurations. And Hypothesis B was acceptable since there was no significant difference between the single numerical configurations for RT.

![Reaction Time - Group](image)

**Figure 1. Reaction Time - Group Main Effect**

The two-way (5×4) mixed model analysis of variance (ANOVA) was conducted, whereby the group variable was the between subjects factor and the trial effect was the
within subjects factor. The means did not differ significantly for RT; $F(4,55) = .4524$, $p = .7702$. Due to this insignificance, a post-hoc test was not warranted. Therefore, the RT of all five groups were basically equal.

**Reaction Time - Session Main Effect**

For productivity performance on RT, the means were found to be 1.844, 1.574, 1.442, and 1.359 for each trial respectively, regardless of the group type. A graph of the means are represented in Figure 2. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 135.892$, $p < 0.001$.

![Reaction Time - Trials](image)

**Figure 2.** Reaction Time - Session Main Effect

The Tukey post hoc test was conducted. Significant differences were found between all the RT sessions; 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4. Therefore as the number of sessions increase, the RT of each student decreases.
Reaction Time - Interaction Effect

The means were found to be 1.746, 1.758, 1.951, 1.892, and 1.872 for the first trial, 1.471, 1.665, 1.600, 1.533, and 1.600 for the second trial, 1.396, 1.402, 1.478, 1.415, and 1.518 for the third trial, and 1.288, 1.283, 1.418, 1.366, and 1.443 for the fourth trial, for groups C, T, CC, TT, and CT respectively. A graph of these means are displayed in Figure 3. The ANOVA results proved no significant differences for the combination of sessions, and type of keypad configuration; $F(12,165) = 1.693, p = .072$. Due to this non-significance, no post hoc test was warranted. Therefore the RT of each group for this analysis are essentially equal to each other.

Figure 3. Reaction Time - Interaction Effect

It was therefore concluded that the RT of the students in all five groups remained relatively equal to each other. Secondly, the RT of each group decreased as the number of sessions increased. Lastly, the combination of sessions and type of keypad configuration utilized by each group also remained relatively equal to each other.
**Mean Time per Keystroke - Group Main Effect**

For productivity performance on the MTK, the means were found to be .620, .699, .641, .721, and .734 for the groups C, T, CC, TT, and CT respectively, regardless of the trial number. Figure 4 depicts a graph of the means. Due to Hypotheses A and B, the seven original planned comparisons were conducted for MTK. A significant difference was found between group C and CT; \( p = .038 \). No significant differences were found between groups C and T, C and CC, C and TT, T and CC, T and TT, and T and CT.

Due to the result of the planned comparisons, Hypothesis A proved to be incorrect; even though there was a significant difference between C and CT, there was no overall significant difference for MTK for the single numerical configurations and the double numerical configurations. Hypothesis B remained acceptable since there was no significant difference between the single numerical configurations for MTK.

![Mean Time per Keystroke - Group](image)

**Figure 4.** Mean Time per Keystroke - Group Main Effect

The two-way \((5 \times 4)\) mixed model analysis of variance (ANOVA) was conducted for MTK. The means did not differ significantly; \( F(4,55) = 1.7414, p = .1541 \). Due to
this insignificance, a post-hoc test was not warranted. Therefore, the MTK of all five groups were basically equal.

**Mean Time per Keystroke - Session Main Effect**

The means were found to be .7212, .7002, .6565, and .6543 for each trial respectively, regardless of the group type. Figure 5 represents a graph of the means. Results from the ANOVA determined significant differences between the means for each of the four sessions; F(3,165) = 32.8264, p < .0001.

![Mean Time per Keystroke - Trials](image)

**Figure 5.** Mean Time per Keystroke - Trial Main Effect

The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant difference between trial 3 and 4. Therefore as the number of sessions increase, the MTK of each group decreased, until upon reaching trial 3, then each group’s MTK remained relatively constant.
Mean Time per Keystroke - Interaction Effect

The means were found to be .644, .758, .665, .771, and .768 for the first trial, .640, .716, .646, .745, and .754 for the second trial, .602, .671, .625, .683, and .702 for the third trial, and .596, .653, .628, .683, and .711 for the fourth trial, for groups C, T, CC, TT, and CT respectively. The means are presented in Figure 6. The ANOVA outcome concluded no significant differences for the combination of sessions, and type of keypad configuration; F(12,165) = 1.0973, p = 0.3656. Due to this non-significance, no post hoc test was performed.

![Mean Time per Keystroke - Interaction](image)

Figure 6. Mean Time per Keystroke - Interaction Effect

It was therefore concluded that the MTK of all five groups remained relatively equal to each other. Secondly, as the number of sessions increase, the MTK of each student decreases, until upon reaching trial 3, then the MTK of each group remains relatively equal. Lastly, the combination of sessions and type of keypad configuration utilized by each group for MTK, also remained relatively equal to each other.
Total Time - Group Main Effect

For productivity performance on TT, the means were found to be 256.417, 289.688, 267.938, 301.104, and 303.646 for the groups C, T, CC, TT, and CT respectively, regardless of the trial number. Figure 7 depicts a graph of the means. Due to the hypothesis, the original seven planned comparisons were conducted for TT. A significant difference was found between group C and CT, p= .044. No significant differences were found between groups C and T, C and CC, C and TT, T and CC, T and TT, and T and CT.

Due to the result of the planned comparisons, Hypothesis A proved to be incorrect; even though there was a significant difference between C and CT, there was no significant difference for TT for the single numerical configurations and the double numerical configurations. And Hypothesis B remained acceptable since there was no significant difference between the single numerical configurations for TT.

The two-way (5×4) mixed model analysis of variance (ANOVA) was conducted for TT. The means did not differ significantly for the TT between groups; F(4,55) =
1.644, p = .176. Due to the ANOVA non-significance, there was no need for a post-hoc test. Therefore, the total time of all five groups were basically equivalent.

**Total Time - Session Main Effect**

The means were found to be 300.567, 286.850, 274.083, and 273.533 for each trial respectively, regardless of the group type. Figure 8 demonstrates a graph of the means. The ANOVA results concluded a significant difference for each of the four sessions; F(3,165) = 40.091, p < 0.001.

![Total Time - Trials](image)

**Figure 8.** Total Time - Trial Main Effect

The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant difference between trial 3 and 4. Therefore as the number of sessions increase, the mean TT of each group decreases, until upon reaching trial 3, then each group’s TT remains relatively constant.
**Total Time - Interaction Effect**

The means were found to be 270.167, 313.750, 277.500, 324.500, and 316.917 for the first trial, 256.500, 296.500, 269.083, 306.667, and 305.500 for the second trial, 251.417, 277.000, 262.583, 284.000 and 295.417 for the third trial, and 247.583, 271.500, 262.583, 289.250, and 296.750 for the fourth trial, for groups C, T, CC, TT, and CT respectively. The means are represented in Figure 9. The ANOVA results determined no significant differences for the combination of sessions, and type of keypad configuration; F(12,165) = 1.694, p = 0.072. Due to this non-significance, no post hoc test was performed.

![Figure 9. Total Time - Interaction Effect](image.png)

It was therefore concluded that the mean TT of all five groups remained relatively equal to each other. Secondly, as the number of sessions increase, the mean TT of each group decreases, until upon reaching trial 3, then the mean TT of each group remained relatively equal. Lastly, the combination of sessions and type of keypad configuration utilized by each group for TT, also remained relatively equal to each other.
Errors - Group Main Effect

For productivity performance on errors, the means were found to be 4.854, 4.458, 4.083, 4.000, and 5.125 for the groups C, T, CC, TT, and CT respectively, regardless of the trial number. Figure 10 represents a graph of the means. Due to the hypothesis, the original seven planned comparisons were conducted for Errors. The outcome of the planned comparisons proved no significant differences between any of the groups; C and T, C and CC, C and TT, C and CT, T and CC, T and TT, and T and CT. Therefore Hypothesis A proved to be incorrect; there was no significant difference for the Errors for the single numerical configurations and the double numerical configurations. Hypothesis B proved to be acceptable since there was no significant difference between the single numerical configurations for Errors.

![Errors - Groups](image)

Figure 10. Errors - Group Main Effect

The two-way (5×4) mixed model analysis of variance (ANOVA) was conducted. The means did not differ significantly for the errors made between groups; F(4,55) = 0.637, p = .638. Due to this non-significance, a post-hoc test was not needed. Therefore, the errors made by all 5 groups were relatively equal.
Errors - Session Main Effect

The means were found to be 5.833, 4.950, 3.400, and 3.833 for each trial respectively, regardless of the group type. Figure 11 depicts a graph representing the means. Results from the ANOVA determined significant differences between the means for each of the four sessions; F(3,165) = 13.310, p < .0001.

Figure 11. Errors - Trial Main Effect

The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant difference between sessions 1 and 2 and 3 and 4. Therefore, the subjects tended to make more errors during sessions 1 and 2, which are relatively equal to each other, than during sessions 3 and 4, which are also relatively equal.

Errors - Interaction Effect

The means were found to be 5.500, 6.000, 4.583, 5.167, and 7.917 for the first trial, 6.417, 4.750, 4.417, 4.667, and 4.500 for the second trial, 3.833, 3.333, 3.750,
2.250, and 3.833 for the third trial, and 3.667, 3.750, 3.583, 3.917, and 4.250 for the fourth trial, for groups C, T, CC, TT, and CT respectively. Figure 12 demonstrates a graph of the means. The two-way ANOVA was conducted and no significant differences were found for the combination of sessions, and type of keypad configuration; F(12,165) = 1.388 and p = 0.176. Due to this non-significance, no post hoc test was performed.

![Errors - Interaction Main Effect](image)

Figure 12. Errors - Interaction Main Effect

It was therefore concluded that the mean Errors of all five groups remained relatively equal to each other. Secondly, the groups tended to make more errors during sessions 1 and 2, which are relatively equal to each other, than during sessions 3 and 4, which are also relatively equivalent. Lastly, the combination of sessions and type of keypad configuration utilized by each group for Errors, also remained relatively equal to each other.

**Analysis of Function Types**

Productivity performance was analyzed on (a) the function types of D, IN, and EX with respect to RT, MTK and TT, between the five groups of numerical configurations,
and (b) the function type EX with respect to RT, MTK and TT, between the groups with double configurations [CC, TT and CT].

**Group Main Effect for all Function Types**

The two-way (5×4) mixed model analysis of variance (ANOVA) was conducted for each function, whereby the group was the between subjects factor and the trial effect was the within subjects factor. The means did not differ significantly for any of the functions. Due to these insignificant results, no post-hoc tests were warranted. Therefore the RT, MTK and TT, separated by function type, of all five groups, were basically equal.

**Session Main Effect for the Data Function**

**Reaction Time**

For productivity performance on the data function with respect to RT, the means were found to be 2.055, 1.686, 1.553, and 1.463 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 13. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 91.079$, $p < .0001$. 
The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant difference between trial 3 and 4. Therefore as the number of sessions increase, the RT of the data function, of each student decreases, until reaching trial 3, then each student's RT of the data function remained relatively constant.

**Session Main Effect for the Data Function**

**Mean Time per Keystroke**

For productivity performance on the data function with respect to MTK, the means were found to be 0.712, 0.703, 0.642, and 0.656 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 14. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 14.748, p < .0001$. 

![Data Function - Reaction Time - Session Main Effect](image.png)
The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant differences between sessions 1 and 2, and 3 and 4. Therefore as the number of sessions increase, the MTK of the data function, of each student remained constant, except for the decrease between sessions 2 and 3.

**Session Main Effect for the Data Function**

**Total Time**

For productivity performance on the data function with respect to TT, the means were found to be 5.159, 5.099, 4.718, and 4.795 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 15. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 21.634, p < .0001$. 

**Figure 14.** Data Function - Mean Time per Keystroke - Session Main Effect
Figure 15. Data Function - Total Time - Session Main Effect

The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant differences between sessions 1 and 2, and 3 and 4. Therefore as the number of sessions increase, the TT of the data function, of each student remained constant, except for the decrease between sessions 2 and 3.

Session Main Effect for the Internal Number Function
Reaction Time

For productivity performance on the internal number function with respect to RT, the means were found to be 1.766, 1.528, 1.424, and 1.318 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 16. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 67.560, p < .0001$. 
The Tukey post hoc test was conducted. Significant differences were found between all RT sessions; 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4. Therefore as the number of sessions increase, the RT of the internal number function, of each student decreased.

Session Main Effect for the Internal Number Function
Mean Time per Keystroke

For productivity performance on the internal number function with respect to MTK, the means were found to be 0.806, 0.785, 0.672, and 0.663 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 17. Results from the ANOVA proved that the means differed significantly for each of the four sessions; F(3,165) = 3.342, p = 0.021.
The Tukey post hoc test was conducted. No significant differences were found between any of the MTK sessions. Therefore as the number of sessions increase, the MTK of the internal number function, of each student remained relatively constant.

**Session Main Effect for the Internal Number Function**

**Total Time**

For productivity performance on the internal number function with respect to TT, the means were found to be 2.887, 2.752, 2.646, and 2.641 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 18. Results from the ANOVA proved that the means differed significantly for each of the four sessions; \( F(3,165) = 17.476, p < .0001 \).
The Tukey post hoc test was conducted. Significant differences were found between sessions 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4. No significant differences were found between sessions 3 and 4. Therefore as the number of sessions increase, the TT of the internal number function, of each student decreased, until upon reaching trial 3, then each student's TT remained relatively constant.

**Session Main Effect for the External Number Function**

**Reaction Time**

For productivity performance on the external number function with respect to RT, the means were found to be 1.708, 1.504, 1.379, and 1.286 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 19. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 73.553, p < .0001$. 

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**Figure 18.** Internal Number Function - Total Time - Session Main Effect
The Tukey post hoc test was conducted. Significant differences were found between all RT sessions; 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4. Therefore as the number of sessions increase, the RT of the external number function, of each student decreased.

**Session Main Effect for the External Number Function**
**Mean Time per Keystroke**

For productivity performance on the external number function with respect to MTK, the means were found to be 0.715, 0.684, 0.658, and 0.654 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 20. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,165) = 17.500, p < .0001$.  

![Graph showing mean RT across trials](Image)
The Tukey post hoc test was conducted. Significant differences were found between sessions; 1 and 2, 1 and 3, 1 and 4, 2 and 3, and 2 and 4. There was no significant difference between trial 3 and 4. Therefore as the number of sessions increase, the MTK of the external number function, of each student decreased, until upon reaching trial 3, then each students' MTK remained relatively constant.

Session Main Effect for the External Number Function
Total Time

For productivity performance on the external number function with respect to TT, the means were found to be 6.950, 6.493, 6.334, and 6.154 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 21. Results from the ANOVA proved that the means differed significantly for each of the four sessions; \( F(3,165) = 21.354, p < .0001 \).
The Tukey post hoc test was conducted. Significant differences were found between sessions; 1 and 2, 1 and 3, 1 and 4, and 2 and 4. There was no significant difference between sessions 2 and 3, and 3 and 4. Therefore as the number of sessions increase, the TT of the external number function, of each student remained relatively constant, except for the decrease between trial 1 and 2.

**Interaction Effect for all Function Types**

The ANOVA outcome concluded significant differences for the IN with respect to TT, and EX with respect to RT; which were $F(12,165) = 1.999$, $p < .0001$, and $F(12,165) = 2.035$, $p < .0001$ respectively. There were no significant differences between any of the other functions.
For the function IN with respect to TT, the means were found to be 2.517, 3.058, 2.646, 3.229, and 2.983 for the first trial, 2.488, 2.854, 2.617, 2.996, and 2.807 for the second trial, 2.475, 2.679, 2.496, 2.817, and 2.763 for the third trial, and 2.363, 2.621, 2.638, 2.817, and 2.767 for the fourth trial, for groups C, T, CC, TT and CT respectively. The means are presented in Figure 22.

The Tukey post hoc test was conducted. The results concluded: (a) groups T, TT, and CT followed the same downward trend with respect to sessions, while tapering off at the end, and (b) groups C and CC’s overall total time was less than that of groups T, TT, and CT.

For the function EX with respect to RT, the means were found to be 1.579, 1.604, 1.876, 1.717, and 1.767 for the first trial, 1.421, 1.638, 1.588, 1.375, and 1.500 for the second trial, 1.304, 1.342, 1.471, 1.313, and 1.467 for the third trial and 1.158, 1.267, 1.363, 1.242, and 1.400 for the fourth trial, for groups C, T, CC, TT, and CT respectively. The means are presented in Figure 23.
The Tukey post hoc test was conducted. The results concluded: (a) groups C, CC, TT and CT followed approximately the same downward trend with respect to sessions, (b) group C’s overall RT was less than that of the other groups, (c) group CC’s overall RT was more than that of the other groups, and (d) the RT during trial 4 was less than that of the three previous sessions.

**Group Main Effect for the External Number Function**
**Groups CC, TT, and CT**

The two-way (3×4) mixed model analysis of variance (ANOVA) was conducted for each function, whereby the group was the between subjects factor and the trial effect was the within subjects factor. The means did not differ significantly for any of the functions.

Due to these insignificant results, no post-hoc tests were warranted. Therefore the RT, MTK and TT, of the external number function, of groups CC, TT and CT, were basically equal.
Trial Main Effect for the External Number Function - Reaction Time
Groups CC, TT, and CT

For productivity performance on the external number function with respect to RT, the means were found to be 1.786, 1.488, 1.417, and 1.335 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 24. Results from the ANOVA proved that the means differed significantly for each of the four sessions; \( F(3,99) = 46.755, p < .0001 \).

![External Number - RT - Trials graph](image.png)

**Figure 24.** External Number Function - Reaction Time - Session Main Effect - Groups CC, TT and CT

The Tukey post hoc test was conducted. Significant differences were found between sessions; 1 and 2, 1 and 3, 1 and 4, and 2 and 4. There was no significant differences between sessions 2 and 3, and 3 and 4. Therefore as the number of sessions increase, the RT of the external number function, of each student remained relatively constant, except for the decrease between sessions 1 and 2.
Trial Main Effect for the External Number Function - Mean Time per Keystroke
Groups CC, TT, and CT

For productivity performance on the external number function with respect to MTK, the means were found to be 0.735, 0.697, 0.678 and 0.673 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 25. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,99) = 8.964, p < .0001$.

![External Number Function - MTK - Trials](image)

Figure 25. External Number Function - Mean Time per Keystroke - Session Main Effect - Groups CC, TT and CT

The Tukey post hoc test was conducted. Significant differences were found between sessions; 1 and 2, 1 and 3, and 1 and 4. There was no significant differences between sessions 2 and 3, 2 and 4, and 3 and 4. Therefore as the number of sessions increase, the MTK of the external number function, of each student remained relatively constant, except for the decrease between sessions 1 and 2.
Trial Main Effect for the External Number Function - Total Time Groups CC, TT, and CT

For productivity performance on the external number function with respect to TT, the means were found to be 7.135, 6.678, 6.515, and 6.500 for each trial respectively, regardless of the group type. A graph of the means is presented in Figure 26. Results from the ANOVA proved that the means differed significantly for each of the four sessions; $F(3,99) = 13.570, p < .0001$.

The Tukey post hoc test was conducted. Significant differences were found between sessions; 1 and 2, 1 and 3, and 1 and 4. There was no significant differences between sessions 2 and 3, 2 and 4, and 3 and 4. Therefore as the number of sessions increase, the TT of the external number function, of each student remained relatively constant, except for the decrease between sessions 1 and 2.
Interaction Effect for External Number Function
Groups CC, TT and CT

The ANOVA outcome concluded no significant differences between any of the configurations, of the external number function. Due to these insignificant results, no post-hoc tests were warranted. Therefore the RT, MTK and TT, of the external number function, of groups CC, TT and CT, were basically equal.

Summary

In summary, the test results of the experiment concluded:

1. No significant difference between the number of errors and the time required for data entry, for the single numerical configurations (consisting of one keypad) and the double numerical configurations (consisting of two keypads).

2. No significant differences were found between the number of errors and the time required for data entry, for the single numerical configurations.

3. There were some significant differences found with respect to sessions; which displayed an over-all downward trend in (a) keying time, and (b) errors, as the sessions increased.

The test results did not support the research hypothesis that one single numerical configuration, incorporated with many functions, will lead to a higher level of efficiency.
DISCUSSION

The objective of this study was to determine whether the telephone, the calculator, or a combination of both arrangements of numeric digits resulted in superior numeric entry performance of functionally relevant data (i.e., telephone numbers vs. data). The results indicated that there were no significant differences in the methods of numeric data entry with respect to time (reaction time, mean time per sequence, and total time) or the number of errors calculated.

The findings of this study may be attributed to either one or a combination of the following factors.

1. There were no data entry experts among the participants. Experts include people with an extensive amount of experience with either or both of the keypad configurations, such as data entry or telemarketing.

2. The fact that almost all college/university students have access to either or both numeric arrangements, through the use of telephones, calculators, computers, automated teller machines (ATM), etc. In this situation, either of the two layouts would be an acceptable form of numerical entry, as long as the layouts remain consistent. Carey (1988) concluded that consistency of layout and function designation is much more important than the numerical layout itself.
3. The participants may not have put forth their best effort in the data entry task, because the consequences may not have been important enough to them. Consequences are regarded as penalties or rewards.

4. The task given to the subjects may not be difficult enough to distinguish any differences between the numeric layouts.

By finding the most efficient numeric layout, there could be small percentage differences in training time, productivity, and/or errors, that can represent significant cost differences. In today's society, two things are clear about numeric keypads; (a) they will be required to interface or communicate with machines for a long time to come, and (b) people will learn to use any keyboard that will be built.
RECOMMENDATIONS

The non-significant results of this study may be the outcome of several factors, including: (a) a relatively small sample size, (b) fairly easy task, (c) relatively short test period, (d) the effects could have been altered by learning effects, (e) no experts were among the participants, and (f) the consequences were not important enough to the participants.

From all the evidence gathered, the most obvious finding of this study is that additional research is necessary. It is recommended that a direct follow-on to this research could include one or a combination of all these items.

1. Increase the number of subjects in each group.
2. Increase task difficulty. Task difficulty could be obtained by (a) increasing the number of data entries each subject has to make, (b) adding more functions to the input task, and/or (c) inputting data for a longer period of time.
3. Have experts as participants instead of occasional users, to increase the variety of numeric keying experience.
4. Make the keying performance consequences more important to the participant, such as punishing mistakes, or providing incentives.
5. Perform the keying task in the blind; letting the participant know which keypad he/she is utilizing, then provide no visual reference of the keys. This can be accomplished with either experts or occasional users.
By implementing any or all of these suggestions, differences between the numerical layouts may be identified.
REFERENCES


APPENDIX A

Numerical Keypad Configurations
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APPENDIX B

List of Numeric Data
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