Human Factors Engineering Studies of the Design and Use of Pushbutton Telephone Sets

By R. L. DEININGER

(Manuscript received February 16, 1960)

From the user's point of view, what are the desirable characteristics of pushbuttons for use in 500-type telephone sets? The studies reported bear on this question and also on questions of how people process information when keying telephone numbers. Four categories of design features were studied: key arrangement, force-displacement characteristics, button-top design and central office factors. The results indicate that considerable latitude exists for key set design in terms of user performance; however, the preference judgments are more selective. The studies also showed that the manner in which the person acquired and keyed the telephone number influenced performance appreciably.

Technological progress in recent years has brought pushbutton signaling from the telephone set within sight of economic feasibility. What, from the user's viewpoint, are the desirable operating characteristics of the key set which should guide development and manufacture? And how do people process information when they key a telephone number?

I. HUMAN FACTORS PROBLEM

Specifically, we would like to know how pushbutton design influences user speed, accuracy and preference in keying telephone numbers. What design specifications will maximize these three quantities, and how critical is it to achieve these maxima? Also, what other factors influence user information processing in keying telephone numbers? For example: How does performance improve with practice? Does it matter how the number to be keyed is displayed? And are there systematic procedures that users follow in keying numbers?

The design features are discussed in Section III and fall into four groups: (a) key arrangement, (b) force-displacement characteristics, (c) button top design and (d) central office considerations. Observations concerning other factors in keying behavior are presented in Section IV.

II. EXPERIMENTAL APPROACH

The number of possible key arrangements, force-displacement characteristics and button tops is very large — too large to be tested. A selection of characteristics was, therefore, made on the basis of prior knowledge, user expectation and broad engineering requirements, so that we could examine only the region around an expected maximum.

In general, each series of test sessions extended over three to five days and compared variations of one or two characteristics, with all other characteristics being kept constant. At the end of the tests the preferred values of the individual characteristics were incorporated into a single key set. Evaluation of this set provided a check on the interactions of these individual choices and on how well they fitted together.

It was recognized that people's keying experience with each set during the three to five sessions in a series would be limited compared to the years of practice they could get if pushbutton telephones became a reality. However, methodological studies showed that differences on a relative basis between key set designs appeared after a comparatively small amount of experience.

A group of adjustable pushbutton telephone sets was used in the later studies in the series. To build a telephone set for every change in a characteristic would have been prohibitive in cost. Such changes were simulated by use of specially designed universal pushbutton switches (Fig. 1). Each adjustable telephone set contained ten universal switches mounted in an arrangement determined by the face plate employed.

Typically, a sample of 10 to 15 employees at Bell Telephone Laboratories, Murray Hill, N. J., was drawn randomly for each study. These people came to a laboratory test room and used two to five pushbutton telephone sets that differed in several characteristics, keying 10 to 15 standard telephone numbers on a set each day. A different set was used for each daily session until all the sets in the study had been tried, the order of use being dictated by the design of the experiment. The number of individuals used in the later studies was selected to detect small differences among the average keying times, by considering the power of the analysis of variance tests involved (Ref. 1, p. 379 and 425). The error terms for these tests were reduced by removing the effects of practice and of differences among individuals in the analysis of variance.

On the first day the subjects were told the procedure that would be followed and were asked to key accurately and quickly, as if they were

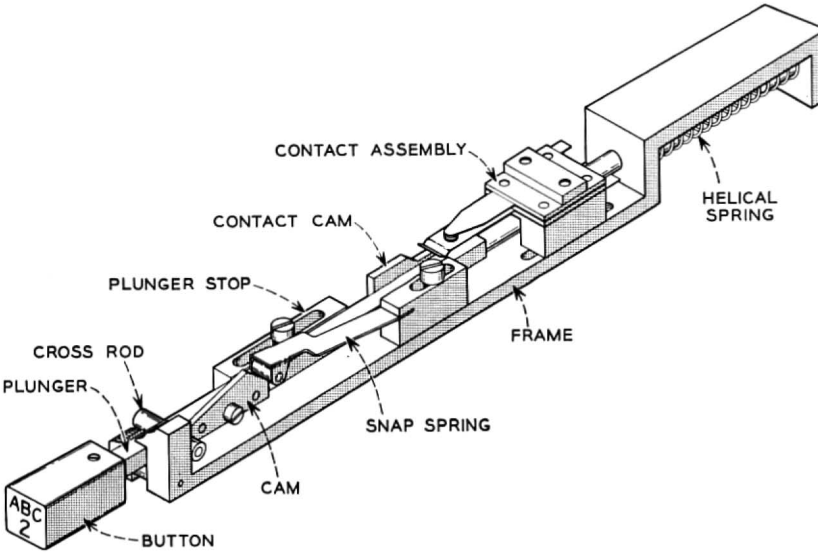


Fig. 1 — The universal pushbutton switch. Changes in force-displacement characteristics were obtained by hand adjustments of the components.

at home or in their office. After trying all conditions in the study, each person was asked for his preferences and for any suggestions he might care to offer. The use of employees in a laboratory-type study seemed justified for two reasons: All comparisons were made within the same study and presumably under constant conditions, and the field trials that followed the laboratory studies would serve to check the findings.

When a person keyed a number, his performance was measured on the equipment shown diagrammatically in Fig. 2. Speed was measured in terms of the keying time, that is, the time interval from the electrical contact of the first key depression until the end of contact of the seventh. Keying accuracy was determined by automatically comparing the number keyed with the number to be keyed. Provisions were made for obtaining more detailed time measures, such as interdigital times and contact durations.

III. THE DESIGN VARIABLES

3.1 *Arrangement of Keys*

The arrangement of the keys was specifically investigated in one study and then checked incidentally in several others. Although other methods

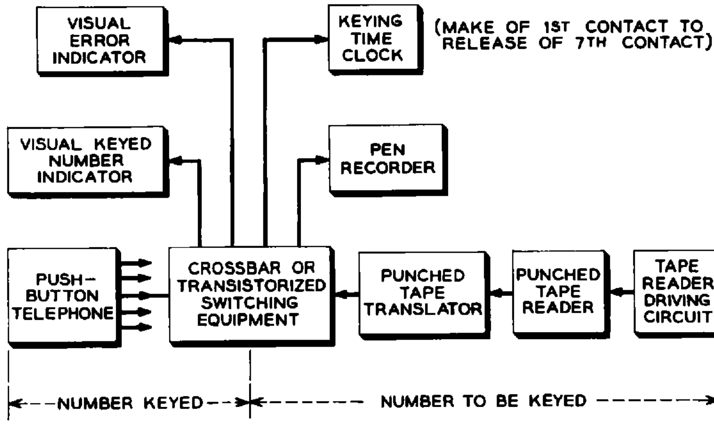


Fig. 2 — Schematic drawing of equipment for measuring and recording keying performance.

were used to make the initial selection of arrangements for the study, performance tests were used to make the final choice because the other methods seemed inadequate. For example, a preliminary study by Lee and Snodgrass[2] showed that there was no significant relation between initial questionnaire preference and subsequent keying performance, and that 10 of the 20 subjects changed their preferences after using the pushbutton telephone sets.

Sixteen different arrangements were selected for the first part of this study. These arrangements were compared by separating them into groups of three and having a different sample of six employees try all three arrangements during each of five sessions. The arrangements and how they were grouped for the study are shown in Fig. 3.

In all the comparisons, only small differences were found in the keying times and errors, and the most preferred arrangements tended to be the best in terms of performance. Significant differences in keying times, errors or preferences were found in four of the six comparisons. Notice that the arrangement frequently found in ten-key adding machines (arrangement I-A, Fig. 3) was not the best of the first three arrangements compared. On the other hand, the same geometric configuration with a different numbering scheme (arrangement IV-A) was superior in keying performance when compared in Group IV. However, the performance differences between the two were small: arrangement I-A had an average keying time of 5.08 seconds, and arrangement IV-A had an average of 4.92 seconds.

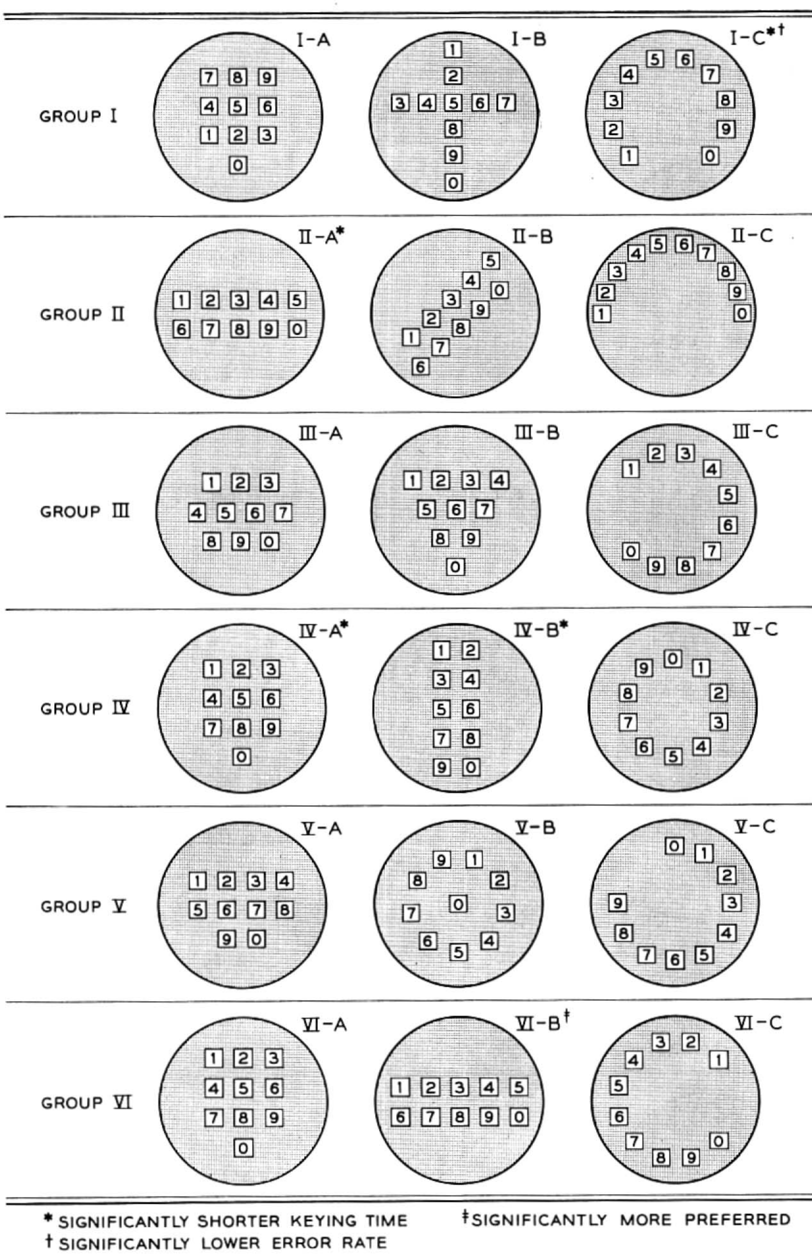


Fig. 3 — The 16 arrangements used in the first study, grouped as they were compared. Two of the arrangements used earlier were compared again in the last group. Although not shown in the figure, the letter groups usually associated with the numbers on a telephone dial were also on the button tops. The tops were $\frac{3}{8}$ inch square with $\frac{9}{64}$-inch-high black letters and numbers on a white background. The circles shown were $4\frac{1}{4}$ inches in diameter.

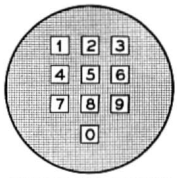
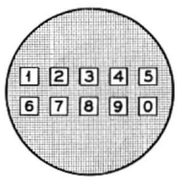
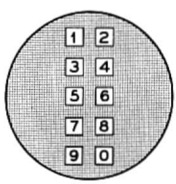
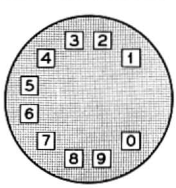
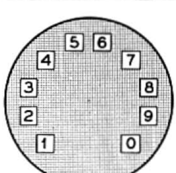
ARRANGEMENT	KEYING TIME (SECONDS)	PER CENT ERRORS	RANKING FOR	RANKING AGAINST
 THREE-BY-THREE PLUS ONE	6.01	2.5	3RD	2ND
 TWO HORIZONTAL ROWS	6.17	2.3	1ST (MOST)	4TH
 TWO VERTICAL COLUMNS	6.12	1.3	5TH (LEAST)	1ST (MOST)
 TELEPHONE	5.90	2.0	2ND	5TH (LEAST)
 SPEEDOMETER	5.97	3.0	4TH	3RD

Fig. 4 — The five arrangements compared in the second study. The specifications listed in the caption of Fig. 3 apply also to this figure.

The four arrangements found superior in their individual comparisons and the arrangement similar to the standard rotary dial (Fig. 4) were used in the next study. In this way, the fastest and most preferred arrangements were compared directly with the standard rotary dial arrangement. The rectangular arrangements had the buttons spaced with $\frac{3}{4}$ inch between centers. The buttons in the circular arrangements were at the ends of $1\frac{1}{2}$-inch radii and were separated by 30°, with the first and tenth buttons being separated by 90°.

A new sample of 15 employees served in three replications of the same Latin square experimental design.[3] No significant differences were found among the keying times even though the study was designed to detect a one-half-second difference among the sets in nine out of ten instances, given the 95 per cent level of confidence and an error term estimated from the previous study. Similarly, no significant differences were found among the error rates. It was concluded that any of the five arrangements was acceptable, but that the arrangement with two vertical columns of keys should be avoided because it was disliked by many subjects.

Although either rectangular or circular arrangements were found acceptable, two of the rectangular arrangements in Fig. 4 offered certain engineering advantages and were studied further. A subsequent study showed that the buttons in the three-by-three-plus-one arrangement could be spaced $\frac{5}{8}$ or $\frac{3}{4}$ inch between centers without significant change in performance (5.56 seconds and 1.7 per cent errors versus 5.54 seconds and 2.5 per cent errors), although preferences indicated the larger spacing was more desirable. The buttons in the two horizontal rows arrangement could be spaced either $\frac{3}{4}$ or $\frac{27}{32}$ inch between centers with little effect on performance (5.33 seconds and 5.8 per cent errors versus 5.63 seconds and 2.5 per cent errors), or on preference.

3.2 *Button Tops*

The button tops used initially in the adjustable pushbutton telephone sets were marginally acceptable from a legibility point of view (see Ref. 4, p. 24). Therefore, a study was conducted to assess the effects of larger letters and button tops on performance and preference. Five combinations of button-top size, letter size and location number size, and pushbutton arrangement were compared (see Fig. 5). Gorton condensed letters and similar numerals were used in the sets, as were the stroke widths recommended by Baker and Grether[4] for the various conditions.

Fifteen randomly selected employees served as subjects in three 5 × 5

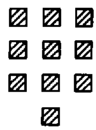
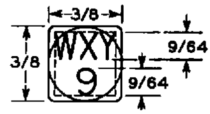
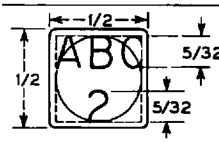
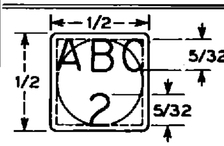
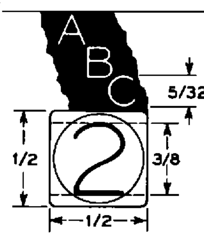
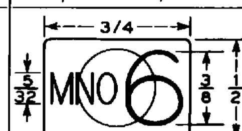
BUTTON ARRANGEMENT	SET AND SPACING	BUTTON AND LETTERING SIZE	REMARKS
 (3X3+1)	SET NO. 1: 3/4 IN. BETWEEN BUTTON CENTERS		KEYING TIME: 6.35 SEC KEYING ERRORS: 7.1% 2 VOTES FOR 9 VOTES AGAINST
	SET NO. 2: 3/4 IN. BETWEEN BUTTON CENTERS		KEYING TIME: 5.83 SEC KEYING ERRORS: 1.3% 1 VOTE FOR 1 VOTE AGAINST
 (5-5-H)	SET NO. 3: 3/4 IN. BETWEEN BUTTON CENTERS		KEYING TIME: 5.75 SEC KEYING ERRORS: 2.0% 4 VOTES FOR 1 VOTE AGAINST
	SET NO. 4: 3/4 IN. BETWEEN BUTTON CENTERS AND LETTERS ON PLATE		KEYING TIME: 5.77 SEC KEYING ERRORS: 3.3% 6 VOTES FOR 4 VOTES AGAINST
	SET NO. 5: 27/32 IN. BETWEEN BUTTON CENTERS		KEYING TIME: 6.07 SEC KEYING ERRORS: 5.3% 2 VOTES FOR 0 VOTES AGAINST

Fig. 5 — The five conditions compared in the lettering study. Both the "votes for" and "votes against" total to 15, the number of subjects in the study.

Latin squares, this number again being based on the power of the test considerations.

Apparently, there is an optimal size for the button tops. Significant differences were found among the keying times and errors, with the smallest tops and lettering being the poorest. Keying with the middle-size tops was superior to that with the smallest tops, regardless of the arrangement of the keys or the location of the lettering. Keying with the large rectangular tops fell between that with the middle-size and that with the smallest-size tops, but did not differ significantly from either. As is apparent in Fig. 5, the differences among the keying times were relatively small, even though they were significant: The largest difference was 0.6 out of 6.0 seconds. The error rates differed significantly from one another; however, a large part of the χ^2 was due to the extremes of 1.3 and 7.1 per cent.

The preferences followed the same pattern as the performances. Subjects stated their dislike of the smallest top and lettering and their preference for the middle size. Placing the letters on the plate rather than on the button top was controversial: Six individuals liked the letters off the top, but four others disliked the idea.

The top of the pushbutton seemed to be important because it served as a display for the associated number and letters and as a target for the key-pressing response. Increasing the size of the top and lettering improved the display. Because the over-all size of the keyset was limited, the larger button tops ultimately required a reduction in the separation between adjacent tops, thereby impairing the qualities of the target.

3.3 *Force-Displacement Characteristics*

While the arrangements were being studied, three aspects of the force-displacement curves were under investigation. Prior to that time, preliminary studies showed that gross variations in the feel of the button had little effect on performance. However, these studies showed force in the neighborhood of 100 to 200 grams and displacements of about one-eighth inch were preferred to larger values.

3.3.1 *Force*

In the first study, the force required to depress the button was varied while the maximum displacement was held constant at one-sixteenth inch. Two conditions were used: medium-touch buttons and light-touch buttons (see the dashed curves in Fig. 6). The forces referred to depended on the helical springs used in the button mechanisms, and Fig. 6 shows static force-displacement curves due mainly to the springs.

A sample of 24 employees used each condition for two consecutive days, half trying the medium-touch buttons first. Only small (0.04 second and 0.8 per cent errors) and insignificant performance differences were found. The preference judgments were somewhat obscured by the fact that the subjects were not told the difference between the two sets until the end of the study and did not have the sets in front of them while they made their judgments. Fifteen persons failed to notice a difference, and meaningful preference information could not be obtained from them. However, of the nine who noticed a difference and had a

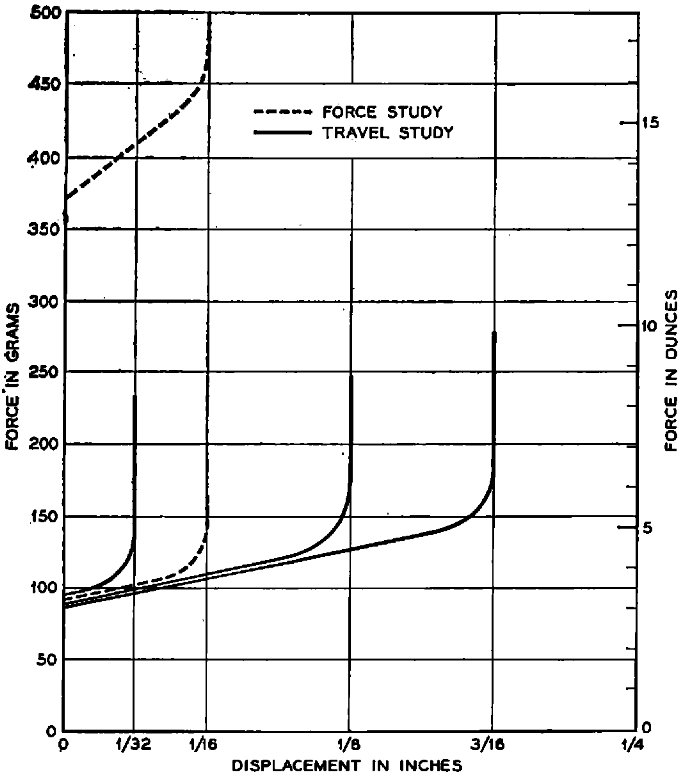


Fig. 6 — The idealized force-displacement curves of the two conditions compared in the study of forces, and the three conditions compared in the study of button travel. These curves are based on essentially static measurements of the universal pushbutton switches.

basis for their preference judgment, eight preferred the light-touch button and one had no preference.

3.3.2 *Travel*

Three conditions of maximum button displacement were compared in the next study. The force was held approximately constant, near 100 grams, and maximum displacements of $\frac{1}{32}$, $\frac{1}{8}$ and $\frac{3}{16}$ inch were compared (see the solid curves in Fig. 6). The point at which the electrical contact was made varied with maximum displacement, so that the contact was closed during 50 per cent of the travel. A new sample of 27 employees tried one condition a day in a cross-over experimental design[3] until all three had been used.

The average keying times ranged from 5.67 to 5.86 seconds and the error rates from 3.9 to 4.1 per cent. No significant differences were found. When asked which condition they most preferred, 11 subjects said the $\frac{1}{32}$-inch displacement, 9 the $\frac{1}{8}$-inch and 6 the $\frac{3}{16}$-inch. Twelve voluntarily stated they did not like a particular condition: eight disliked the $\frac{1}{32}$-inch, one the $\frac{1}{8}$-inch and three the $\frac{3}{16}$-inch. Taking into account both likes and dislikes, the smallest displacement appears controversial, the largest unpopular and the middle the most desirable.

3.3.3 *Feedback*

The next question studied was as follows: What would happen if additional auditory or kinesthetic-tactile feedback were added to a button incorporation desirable values of force and travel? Letting the customer hear the voice-frequency switching signals might provide feedback concerning the adequacy of the button pressings. Moreover, the addition of a slight snap action and a more distinctive bottoming to the pushbutton might improve performance.

For this study, the buttons in one adjustable set had the force and displacement that were found desirable in the two previous studies. The buttons in a second set had the same travel, but had a slight snap action and a bottoming action that terminated movement abruptly and with an audible click. Each of these sets was used with and without the voice-frequency code signals, so that a total of four conditions were studied. Three 4×4 Latin squares were used with 12 employees, who tried one condition a day.

For both performance and preference, the differences among the four conditions were small and insignificant. This study is interpreted as indicating that neither form of additional feedback was necessary in a button mechanism that had desirable force-displacement characteristics.

3.3.4 *Composites of Characteristics*

Because the studies reported thus far investigated one or two of the characteristics at a time, there remained the question whether performance and preference for composites of the characteristics could be predicted from the individual studies. This point was checked in the following study that compared three pushbutton telephone sets, each embodying a different composite of characteristics.

The preferred characteristics isolated by the preceding studies were combined in one of the adjustable pushbutton sets. The other two sets in this study had been designed for various engineering and test purposes before the preferred values were isolated. When the characteristics of these two sets were assessed in terms of the individual human factors studies, it was found that they deviated from the most preferred values but were still largely within the range of desirable and acceptable values. The largest deviations were found in the force-displacement characteristics, but even these were not extreme. Thus, it was predicted that (a) small and insignificant performance differences would be found, but (b) large and significant preference differences would be found, particularly where the force-displacement characteristics of the button mechanism were concerned.

Forty-five employees, none of whom had served in an earlier study, used one set each day to accord with 15 3×3 Latin squares. This sample size was selected to provide a more powerful test of the error rates than was given by the earlier studies and to permit more detailed analysis of the preference judgments.

As predicted, the differences among the average keying times were small and insignificant. An average of 5.8 seconds was required to key a standard telephone number on the most preferred combination versus 5.9 and 6.0 seconds on the other two. However, significant differences were found among the error rates because the electrical contacts on one set were out of adjustment. At least one error was made in keying 2.3 per cent of the telephone numbers on the most preferred composite, in keying 2.0 per cent of the numbers on the second set and in keying 10 per cent of the numbers on the third set. The additional 8 per cent errors were all of one type; when the fault was corrected in later models, more normal error rates were obtained with that set.

The large differences expected among the preference judgments for the three composites were found. In an interview after the last day of testing, the subjects were asked which set they preferred the most and which they preferred the least. Although there were no significant differences among the first place votes, the set with the most preferred characteristics was rated as "least liked" by significantly fewer people than either of the two other sets. The subjects were then asked which button feel they liked the most and which they liked the least. Again, the set with the most preferred characteristics came out ahead: not a single person disliked the feel of its mechanisms.

In a sense, this study served to validate the procedure adopted in this series, since it showed that the desirable characteristics isolated in the individual studies could be combined into a superior set. Very likely, this was because much the same procedure was used throughout the entire series. Also, the fact that the characteristics of the other two sets were close to the characteristics investigated in the individual studies facilitated agreement between the predictions and the results.

3.4 *Central Office Factors*

How long the customer holds the pushbutton in contact and how long he pauses between consecutive key pressings are important in the design of central office switching equipment. Of primary concern are short contact durations and brief interdigital times. Some data regarding these two intervals were gathered in two studies.

Fifteen employees keyed a total of 1500 seven-character all-numeral numbers on each of two pushbutton telephone sets in the first study. These sets were prototypes of operating equipment and differed in three characteristics: the arrangement of the keys, the force required to depress the keys and the point at which the electrical contact was made as the button was being depressed.

Keying was about as fast on one set as on the other; however, the contact durations were shorter and the interdigital times longer on one set than on the other (see Fig. 7). This differential proportioning of the time seems to reflect the relative location of the electrical contact in the travel of the button as indicated in the figure. The results of this study agree with the results of a preliminary study in which five prototype key sets were studied. Thus, it may be possible to lengthen the contact duration by increasing the percentage of button travel during which contact is made.

Very brief contact durations did occur; for example, durations equal to or less than 0.042 second occurred in 1 per cent of the key pressings. The interdigital times were longer, and 1 per cent of them fell at or below 0.090 second. The occurrence of short time values depended on the person doing the keying, particularly for the interdigital times, where most of the short values were due to one individual. Another source of

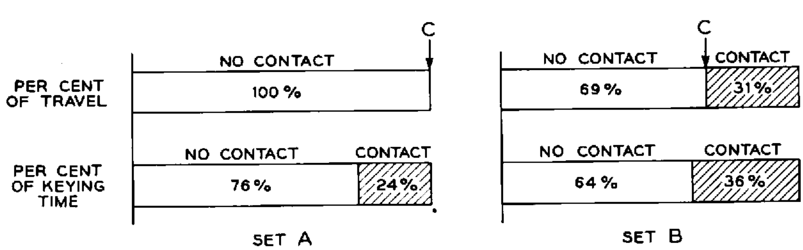


Fig. 7 — The effect of the location of the electrical contact on the percentage of keying time during which contact was made.

short interdigital intervals was a repeated character in the number to be keyed. The interdigital time for repeated characters averaged 0.100 second less than the times for nonrepeated characters.

A second set of detailed measurements, taken during part of the study of composites, showed more clearly that brief contact durations and interdigital times were associated with fast keyers. The last ten keyings made by 30 of the 45 individuals using one of the prototype sets were recorded, equipment permitting. The correlations among the average contact duration, the average interdigital time and the average keying time for each subject were computed after the averages were transformed logarithmically to reduce the skewness of the distributions. The average keying time correlated 0.47 with the average contact duration and 0.76 with the average interdigital interval. No relation was found between the contact duration and the interdigital time. The correlation coefficients indicate that fast keyers tend to have shorter contact durations, and definitely make shorter interdigital pauses. This latter point will be discussed in greater detail in a moment, for it seems related to the procedure that each subject adopted in keying numbers.

IV. OBSERVATIONS ON KEYING BEHAVIOR

When a person keys a telephone number he is processing information in a very literal sense. The standard telephone number contains 22.3 bits of information; on the basis of the key pressings, the central office switching equipment selects one line and completes the call. The physical characteristics of the pushbutton key set are one factor that influences the efficiency of the information processing. As was reported in Section III, the speed and accuracy of performance were affected by the arrangement of the keys and the size of the button tops. Moreover, if larger forces and longer displacements were studied, or if more powerful experiments were used, significant effects very likely would be found for the force-displacement characteristics as well.

4.1 *Additional Factors That Influence Performance*

The studies reported here and studies made by other groups at the Laboratories have pointed to additional factors that influence the efficiency of information processing. In the case of unfamiliar numbers, the manner in which the number is displayed is important. Keying unfamiliar numbers from the pages of a telephone directory can increase the keying times by 75 per cent and the keying errors by 100 per cent in comparison with keying from a 3- × 5-inch file card on which only one number is typed. The amount of information to be processed is also a factor; for example, about 4 seconds more is required to key a seven-character telephone number than a four-character one. Familiar numbers and numbers with repeated characters or simple sequences of digits are keyed quickly and accurately.

Experience with pushbutton keying facilitated the information processing. Keying became faster as people used the key sets day after day. However, performance seemed to improve at about the same rate whether they used the same set each day, the same two or three sets each day, or a different set each day. Some of this improvement was due to increased familiarity with the test room and procedure, but similar improvements with practice appear in field trials, indicating that experience in using pushbuttons is important. In the case of keying accuracy, the low error rates make detection of any learning trends difficult.

Perhaps the most important factor in the information processing is the individual himself. Some people keyed seven-character telephone numbers in less than two seconds, requiring about 2.7 seconds on the average, and others required as high as 12.4 seconds on the average to key the same numbers. These differences were consistent from day to day and from telephone to telephone, as can be gathered from the following rank-order correlation coefficients: There was a 0.8 correlation between pushbutton keying times on day 1 and pushbutton keying times on days 12 through 14, a 0.7 correlation between pretest rotary dialing times and pushbutton keying times on day 1 and 0.6 correlation between pretest dialing times and pushbutton keying times on days 12 through 14. The keying times on two different pushbutton sets were more highly correlated than rotary dialing times and pushbutton keying times.

4.2 *The Importance of the Keying Process*

The large differences among the average keying times for individuals are largely due to the ways in which people acquire and key telephone numbers. It is a question whether they memorize the entire number and key it without referring back to the display, or whether they memorize and key the first part of the number and then refer back to the display to memorize the remainder for keying. Detailed analysis of the interdigital times shows that the intervals for the fastest subject vary only slightly (see Fig. 8). The interdigital times for average-speed keyers show a distinct increase between the third and fourth characters. This accounts for the fact that the average keying time is more highly cor-

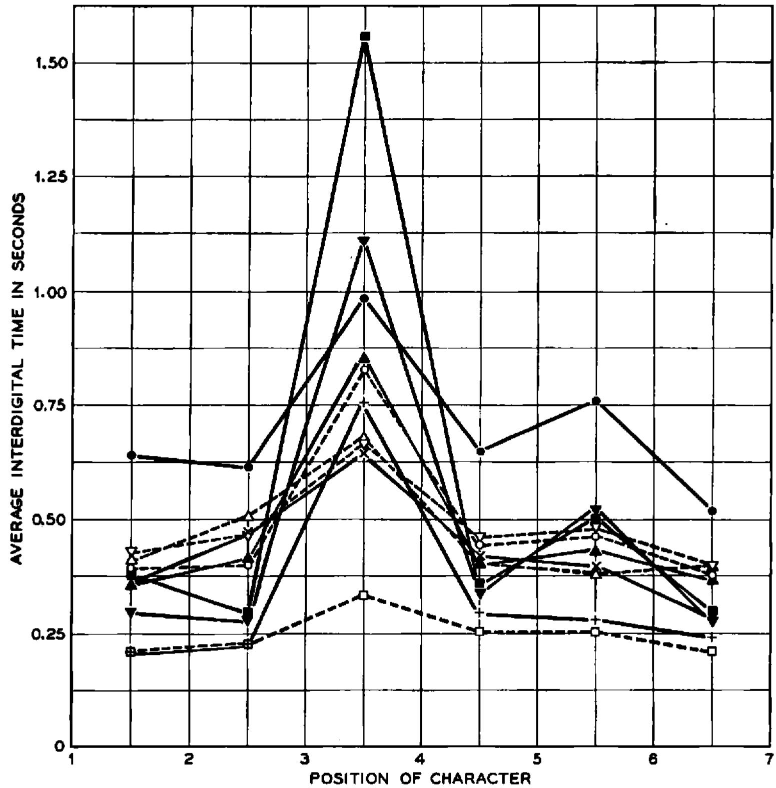


Fig. 8 — Average interdigital intervals for individual subjects keying seven-character numbers. The interdigital intervals were measured from the breaking of one electrical contact to the making of the next contact. (These results were obtained for all-numeral dialing; data for letter-and-numeral dialing are similar but less definitive than those shown in the figure.)

related with the interdigital time than with the contact duration. These findings corroborate the statements made by people about how they key telephone numbers. The fastest say that they memorize and key the entire number without referring back to the display, whereas the average to slow keyers say that they refer back in the middle of keying the number.

4.3 *Why Refer Back?*

Neither method of keying seems more accurate than the other. One might predict that keying without referral would be less accurate and therefore that fast keyers would make more errors than slow keyers. However, no relation between keying time and errors could be detected among the studies reported, regardless of whether they were considered singularly or as a group for analysis. The absence of a correlation between time and errors in the present studies must be interpreted cautiously, since these studies were not designed to detect such relations.

On the other hand, referral does serve an important purpose, as indicated by the following study. A sample of six employees was asked to key telephone numbers with referral during two sessions and without referral during two other sessions. When keying without referral, the individuals were asked to memorize the entire number, turn over the display card, and key the number from memory. A total of 156 standard telephone numbers were keyed under each set of instructions. Some subjects found it very difficult to key telephone numbers without referral. These people said they usually dialed unfamiliar telephone numbers by breaking them into two or more parts. The difficulty they experienced was reflected in their error rates. There was a drop in keying accuracy as more and more of the characters in the number were keyed, and this drop was due primarily to those who said they usually dialed with referral (see Fig. 9). Apparently, if a person habitually keys with referral,

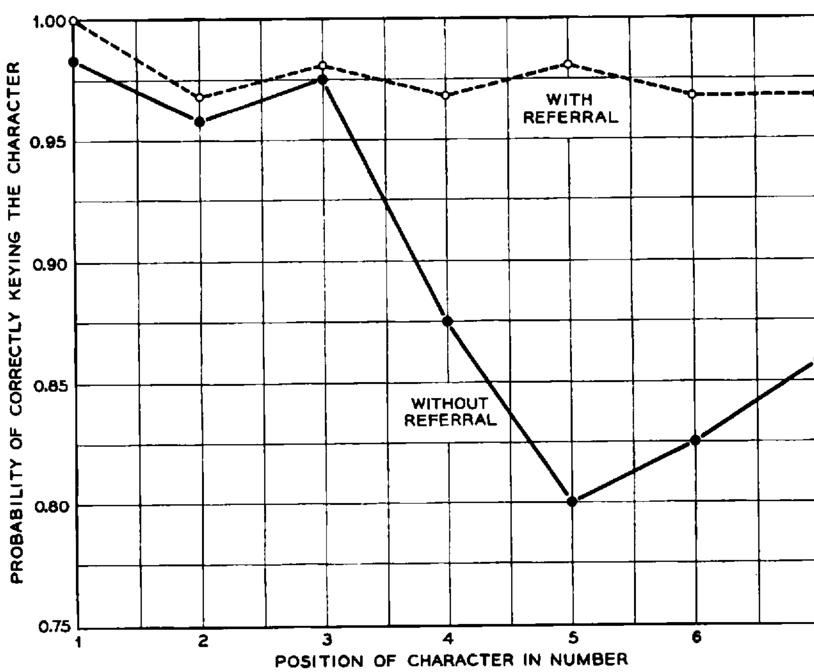


Fig. 9 — Accuracy of keying as a function of position of character for two methods of keying. The number display was always present during keying with referral, but it was removed before keying started for keying without referral.

he does so to increase the accuracy of keying the latter characters in the telephone number, even though his over-all keying accuracy is not appreciably greater than that of a person who usually keys without referral.

V. CONCLUSIONS

Regarding the design of pushbutton telephone key sets that are fast, accurate and convenient to use, the following statements can be made:

i. The operating characteristics of the key sets significantly influence both keying performance and user preference.

ii. In terms of keying performance there exists a rather broad region of desirable values for the operating characteristics. Thus, there is latitude for telephone key sets and, so long as the characteristics remain in the region of desirable values, little deterioration in keying performance will be found.

iii. Considerably less latitude exists if preferences are considered, particularly in the case of the force-displacement characteristics. Typically, subjects preferred a smooth and quietly operating button with a light touch and a moderate travel.

Other factors that influence keying performance are practice, number length and display media, and familiarity with the telephone number. On the other hand, the most important factor influencing performance observed in these studies was the manner in which the subject acquired and keyed the number. A person who memorized the entire number and keyed it without referring back to the display could key a number in less than two seconds. However, a person who memorized part of the number, keyed it and then referred back to the display to memorize and key the remainder of the number could require more than 12 seconds to key the same number.

VI. ACKNOWLEDGMENTS

Many individuals contributed to the studies reported. In this group were Miss N. L. Bowles, P. D. Bricker, Mrs. S. L. Ferguson, O. O. Gruenz, Miss V. A. Hansen, Miss M. J. Kellogg, Miss E. T. Leddy, W. A. Lee, S. E. Michaels, W. A. Munson, R. R. Riesz, Mrs. S. B. Sheppard, Miss J. G. Snodgrass, Miss C. M. Steadler and C. H. Sturner.

The author would like to thank J. E. Karlin for his advice in conducting the latter phases of the program and in writing this report.

REFERENCES

1. Hald, A., *Statistical Theory with Engineering Applications*, John Wiley and Sons, New York, 1952.
2. Lee, W. A. and Snodgrass, J. G., On the Relation Between Numbering Preferences and Performance on a Ten-Button Keyboard, Amer. Psychol., **13**, 1958, p. 425.
3. Federer, W. T., *Experimental Design*, Macmillan, New York, 1955.
4. Baker, C. A. and Grether, W. F., Visual Presentation of Information. Wright