CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

FEEDBACK AND KEY DISCRIMINATION
ON MEMBRANE KEYPADS

A thesis submitted in partial satisfaction of the
requirements for the degree of Master of Arts in

Psychology

by

Cynthia Jean Roe

January 1984

The Thesis of Cynthia Jean Roe is approved:

Mark S. Sanders. Ph.D.

Donald C. Butler. Ph.D.

Tyler Blake, Ph.D. (Chair)

California State University, Northridge

To my father

ACKNOWLEDGMENT

My deepest thanks to Marc Hollingsworth of Micro Switch, Ken Croston of Croston Electronics and to Dr. William H. Muto and Dr. James C. Gutmann of Xerox Corporation. Without their encouragement and assistance, this project would not have been possible.

And deepest thanks to Dr. Tyler Blake, Dr. Don Butler, Dr. Irv Streimer and Dr. Mark Sanders. Their continual support and encouragement throughout my program helped me grow both personally and professionally.

And thanks to Gary Albarian. His friendship saw me through it all.

TABLE OF CONTENTS

DEDICATION	iii
ACKNOWLEDGMENT	iv
ABSTRACT	ix
INTRODUCTION	1
Push-buttons and feedback	1
Push-button key discrimination	3
Membrane keypads and feedback	3
Membrane key discrimination	4
Hypotheses	6
METHOD	6
Subjects	6
Apparatus	6
Independent variables	9
Experimental design	9
Procedure	9
Paired comparisons	9
Comparative rating scales	11
Keying task	11
Semantic differential & 1-10 rating scales	12
RESULTS	12
Paired comparisons	12
Comparative rating scales	17
Keying time	21
Keying errors	22
Semantic differential & 1-10 rating scales	26
Correlations between performance & preference measures	29
DISCUSSION	29
Limits to generality of results	35
Summary	35
REFERENCES	37
APPENDIX 1. Instructions to Part I	38
APPENDIX 2. Instructions to Part II	39
APPENDIX 3. Comparative Rating Scales	40

TABLE OF CONTENTS (Continued)

APPENDIX 4.	Keystroke Combinations	42
APPENDIX 5.	Stimulus Sequences	44
APPENDIX 6.	Instructions to Part III	45
APPENDIX 7.	Keypad Evaluation Form	46
APPENDIX 8.	Background Questionnaire	47

LIST OF FIGURES

Figure	Title	Page
1.	Membrane keypad construction with and without a dome	2
2.	Configuration of the keypad testing device	7
3.	Keypad dimensions, character assignment and mechanical specifications	8
4.	Median ranks of the paired comparison data	15
5.	Median ranks of the paired comparison data	16
6.	Median ranks of the comparative rating scale data	20
7.	Median ranks of the omission error data	25
8.	Median ranks of the omission error data	27

LIST OF TABLES

Table	Title	Page
1.	Experimental design	10
2.	Paired comparison data	13
3.	Comparative rating scale data with tone off	18
4.	Comparative rating scale data with tone on	19
5.	Analysis of variance for total keying time data	23
6.	Omission error data	24
7.	Analysis of variance for keypad acceptability ratings	28
8.	Spearman Rho correlations	30
9.	Summary of results	32

ABSTRACT

FEEDBACK AND KEY DISCRIMINATION ON MEMBRANE KEYPADS

by

Cynthia Jean Roe

Master of Arts in Psychology

This study investigated the effects of visual and tactile key discrimination and kinesthetic and auditory feedback on membrane keypads. More specifically, metal domes, embossed key edges and tone were examined.

Fortyeight subjects were used in a 2 x 2 x 2 factorial design with two levels of key discrimination (with and without embossed key edges), two levels of kinesthetic feedback (with and without metal domes), and two levels of auditory feedback (with and without a 1000 Hz tone). Several types of preference scales along with keying time and error rate were used as comparative measures. Results indicated that key discrimination provided by embossed key edges and feedback provided by metal domes and auditory tones had a significant effect on keying performance and operator ratings of membrane keypads. Auditory feedback paired with tactile and/or kinesthetic feedback yielded the best performance and preference scores.

Feedback and Key Discrimination

On Membrane Keypads

Membrane keypads have replaced mechanical push buttons on many consumer and industrial products. A membrane keypad consists of a conductive membrane which is separated from shorting pads by less than 1 mm. When a key is lightly pressed, the conductive circuitry is brought into contact with a shorting pad which closes the circuit and activates the switch (see Figure 1).

Research to date has extensively explored variables concerned with mechanical push-buttons (Deininger, 1960; Alden, Daniels & Kanarick, 1972). A number of human factors handbooks provide detailed data and design principles covering the area (Seibel, 1972; Woodson, 1981). In contrast, a marked paucity of literature addresses variables introduced by membrane keypads. Unfortunately, many design decisions regarding membrane-switch panels are based on "what-feels-right" rather than results of controlled research. The present study will focus on design issues related to membrane keypads, with particular emphasis on feedback and key discrimination.

Push-buttons and feedback. It has been repeatedly shown that a major source of feedback for the operator of push-button mechanisms is the tactile feedback provided by key displacement (Seibel, 1972). The expected consequence of a push is the tactile response which push-button travel provides. Additional feedback (visual, auditory or kinesthetic) does not appear to improve performance on conventional push-button keyboards (Alden et al., 1972). Deininger (1960) found that snap-action (an increase in required force followed by a sharp decrease in force during a keystroke)

Figure 1. Membrane keypad construction with and without a dome and embossed key edge

3

and audible tones did not affect keying speed, error rates or operator preference on push-button telephones. Similarly, Pollard and Cooper (1979) studied the effects of several types of tonal-feedback (no tone, an 820 Hz single tone and a click-on-depression) and found no significant differences among conditions during push-button keying tasks.

Push-button key discrimination. Key characteristic such as shape, size, color and placement can be used as effective key discrimination cues. For example, proper finger placement can be enhanced by concave key surfaces and adequate key separation [approximately 0.75 inches (19.05 mm) between key centers] (Seibel, 1972; Woodson, 1981). For flat, rectangular push-buttons located directly adjacent to one another, Woodson (1981) recommends 0.24 cm separator bars to prevent the operator's finger from accidentally pressing neighboring buttons.

Keyboard push-buttons typically extend out from their panel. This extension in itself offers three-dimensional visual and tactual discrimination cues. Contrasting colors chosen for keys and panel are further ways of providing visual discrimination.

Membrane keypads and feedback. Membrane keypads lack much of the feedback which would normally be available using conventional push-button mechanisms. For example, flat keypads require an operator's finger to travel only 0.006 - 0.008 inches (0.15 - 0.20 mm) compared to standard push-button travel of 0.05 - 0.25 inches (1.27 - 6.35 mm). Consequently, operators lose the substantial tactile feedback provided by push-button key displacement.

Metallic or polyester domes can be incorporated into membrane key mechanisms to provide travel [0.010 - 0.040 inches (0.25 - 1.02 mm)],

bottoming snap-action and auditory feedback to membrane keys. These domes can also enhance visual key discrimination by raising keys slightly above the panel's surface (see Figure 1). Only a few researchers have addressed the issue of adding travel and snap action to membrane keypads. Preliminary findings appear to indicate that keying performance improves when such travel and action is added (Thomas, 1982). For the most part, studies involving membrane keys have been conducted within industrial settings and are proprietary.

Other sources of feedback, such as visual and auditory feedback, may also prove to be useful with membrane keypads. Pollard and Cooper (1979) found that auditory feedback can improve keying performance on capacitance keys. Like membrane switches, capacitance keys remove the naturally occurring sound and feel of button operation. Capacitance circuitry is activated even before an operator's finger touches a key surface. Pollard and Cooper looked at the effects of three types of feedback used with capacitance keypads. They found an 820 Hz tone to produce superior performance over a click-on-depression feedback or visual feedback (illumination of a panel above the keypad).

Membrane key discrimination. Variables that affect discrimination of keys are dramatically altered when membrane keypads are used instead of mechanical push-buttons. In contrast to push-button keyboards, conventional membrane panels are usually flat and offer no tactile cues to differentiate keys. Many membrane panels differentiate keys solely by the visual cues of color contrast and printed graphics.

Similar in function to separator bars, overlays can be placed over membrane panels to physically separate individual membrane keys. Such

"key-locator" overlays usually consist of a 0.010 - 0.080 inches (0.25 - 2.03 mm) thick sheet of polyester. Keypads are exposed through cut-out areas and can be located by touch. Embossed ridges around keys provide similar separation cues (see Figure 1). Embossed ridges and overlays provide three-dimensional visual and tactile key separation to enhance positive finger positioning.

Few researchers have addressed the issue of key discrimination of membrane keypads. Pollard and Cooper (1979) compared keying performance on a capacitive keypad (which delineated keys via a black line grid) to a membrane keypad (which delineated keys via a black overlay). Both panels were mounted on standard telephone instruments. Subjects dialed 25 10-digit numbers on each type of keypad. The time taken to key each 10-digit sequence from the first button depression to last button release was recorded. Keying times on the membrane panel were significantly less than on the capacitive panel. The authors suggested that the sensitivity of the capacitance activation mechanism might have caused operators to hesitate prior to key activation. The authors did not address the overlay as a contributing variable.

Spencer (1981) tested keying performance on membrane keypads under three overlay conditions. Two keypads had black overlays of different thicknesses: the thin overlay measured 0.006 inches (0.15 mm); the thick overlay measured 0.060 inches (1.52 mm). The third keypad had no overlay; white keys on this panel were outlined in black. All the keypads were mounted on standard telephone instruments. Subjects keyed 20 7-digit numbers on each keypad. Keying times were measured from the time the first key was depressed to the last key released. Neither keying

times nor preference scores were found to differ significantly. Significantly more errors, however, were made with the thick overlay condition.

Hypotheses. The present study will address the key discrimination provided by embossed key edges and feedback provided by domes and auditory tones on membrane keypads. It was predicted that these feedback and discrimination features would be preferred by users and would improve keying performance. The study was intended to focus on keys used for infrequent functions. Results were intended to be generalized to membrane keys used in such tasks as inputting minutes on a microwave oven or checking electronic mail at an executive work station.

Method

Subjects. Twenty-four males and 24 females (Xerox employees and temporary office personnel) served as subjects in this study. Subjects ranged in age from 20-60 with 12-18 years of education. Professions ranged from part-time typists to corporate executives. Typing speeds ranged from 15-90 words per minute. No subjects had automatic 10-key skills.

Apparatus. The four 16-key membrane keypads used in this study were provided by Micro Switch Corporation. Keypads included ten number keys (zero to nine) and six alphabet keys (A to F). An ENTER label was placed under each "A" key and a CLEAR label was placed under each "B" key. The keypads and four red LEDs were mounted on a panel set at 25° to the horizontal (see Figure 2). Keypad dimensions, mechanical specifications and layout are provided in Figure 3.

A Xerox 820-II computer was used to display stimulus material and record all key operations.

Figure 2. Configuration of the keypad testing device

Travel: 0.016 in. (0.41 mm) with dome
 0.010 in. (0.25 mm) without dome
 Operating Force: 12 oz. with dome
 8 oz. without dome

Figure 3. Keypad dimensions, character assignments and mechanical specifications

Independent variables. Three independent variables were examined: metal domes, embossed key edges and tone. Keys without metal domes had travel of 0.01 inches (0.25 mm) and an operating force of 8 ounces. Keys with domes had travel of 0.016 inches (0.41 mm) and an operating force of 12 ounces (see Figure 3). Keys without embossed edges were completely flat. Keys with embossed edges were outlined with a raised surface which provided visual and tactile key separation cues (see Figure 3). An electronically generated 1000 Hz tone, 50 ms in duration, provided auditory feedback.

Experimental design. This experiment was a 2 x 2 x 2 factorial design with two levels of tactile key discrimination on the keypad's surface (with and without embossed key edges), two levels of key action (with and without metal domes), and two levels of auditory feedback (with and without tone). The experimental design is shown in Table 1.

Procedure. Four preference measures and two performance measures were used to compare the eight keypad conditions. Paired comparisons and Comparative Rating Scales were administered after subjects keyed a few digits on each keypad. Performance was then measured during keying task that lasted several minutes. After this exposure to one keypad condition, subjects were asked to complete several rating scales concerning the keypad they used during the keying task. The following describes each measure in more detail:

Paired comparisons. Each subject was seated in front of the keypad testing device and asked to read typewritten instructions (see Appendix 1). Subjects were asked to key in a few digits on two selected keypads and indicate which they preferred. All pairwise combinations of the eight

Table 1
Experimental Design

	<u>No Dome</u>		<u>Dome</u>	
	No embossing	Embossing	No Embossing	Embossing
No Tone	Keypad 1	Keypad 2	Keypad 3	Keypad 4
Tone	Keypad 5	Keypad 6	Keypad 7	Keypad 8

conditions were made - 28 comparisons in all. Presentation orders were randomized.

Comparative rating scales. After the paired comparisons were completed, subjects were asked to rate several of the keypad conditions on linear scales ranging from "best" to "worst" (see Appendices 2 and 3). Keypads 1, 2, 3 and 4 (all no-tone conditions) were rated on one scale. Keypads 5, 6, 7 and 8 (all tone conditions) were rated on a separate scale.

Keying task. In the next phase of the experiment, subjects were asked to key a block of alphanumeric sequences on one of the eight keypad conditions. Three males and three females were randomly assigned to each of the conditions.

Fifty 5-digit alphanumeric sequences were keyed by each subject. All possible inter-key movements on the 16-key keypad were categorized by center-to-center distance and direction-of-movement (see Appendix 4). The 50 trial sequences were created so that every possible type of travel was represented (see Appendix 5). To insure task equivalency, each subject received the same sequences (order of sequence presentation was randomized).

Typewritten procedures for this phase of the study (see Appendix 6) instructed subjects to press ENTER on the keypad under the red light when they were ready for the first sequence to appear on the screen. After memorizing the sequence, the subject keyed the digits on the designated keypad (followed by a depression of the ENTER key). Instructions called for both speed and accuracy. The stimulus sequence was erased from the screen when the first key depression occurred. When the ENTER key was depressed, the computer compared the keyed sequence to the

stimulus sequence. If the sequence was keyed correctly, the next sequence appeared on the screen. If an error was made, the same sequence reappeared on the screen. Subjects were told in the instructions to expect such repeated sequences when an error was made. They also were told that if they detected their own error or forgot the sequence, they could use the CLEAR key to clear any sequence. Depression of the CLEAR key caused the previous sequence to reappear on the screen. Subjects were given five practice trials to insure that the procedures were clearly understood. The keying task continued until all 50 sequences in the trial block were keyed correctly. All keystrokes and interkey times were recorded.

Semantic differential and 1-10 rating scales. In this last phase of the study, subjects were asked to complete an evaluation form concerning the keypad they used during the keying task. Seven-point semantic differential ratings were obtained on the following scales: hard to push keys/easy to push keys, annoying/pleasant, strange/familiar, slow to respond/quick to respond, tiring/restful, undesirable/desirable, sluggish/lively, frustrating/enjoyable, hard to locate keys/easy to locate keys, worst/best and unacceptable/acceptable. Evaluation forms also included a 1-10 rating scale where 10 was to be considered "the best possible keypad" and 1 was to be considered "the worst possible keypad" (see Appendix 7).

Results

Paired comparisons. The paired comparison data were ranked and analyzed with a 2-way Friedman Rank Sums Test (Hollander & Wolfe, 1973). Table 2 shows the eight keypad conditions that were compared and their respective median ranks. A significant difference was found

Table 2
Paired Comparison Data

	Keypad condition							
	Keypad 1 no tone no dome no emboss	Keypad 2 no tone no dome emboss	Keypad 5 tone no dome no emboss	Keypad 3 no tone dome no emboss	Keypad 4 no tone dome emboss	Keypad 7 tone dome no emboss	Keypad 6 tone no dome emboss	Keypad 8 tone dome emboss
Median rank*	8	7	5.5	5	3.75	3	3	2
Non-significant differences								

* 1=most preferred 8=least preferred

between conditions, $\chi^2 (7) = 178, p < .001$. At a probability error rate of .01, a distribution-free multiple comparison test based on the Friedman rank sums was used to determine which keypads were preferred. Table 2 shows the results.

Figure 4 shows that when the effect of dome is isolated (holding the state of embossing and tone constant across comparisons), operators selected keypads with domes more frequently than keypads without domes (except when tone and embossing were both present) [keypad 3 < keypad 1, keypad 4 < keypad 2, keypad 7 < keypad 5, keypad 6 = keypad 8]. When the effect of embossing is isolated (holding the state of dome and tone constant across comparisons), operators showed no preference between embossed and non-embossed keys (except when tone was on and domes were not present) [keypad 6 < keypad 5, keypad 1 = keypad 2, keypad 3 = keypad 4, keypad 7 = keypad 8]. Figure 5 shows that when the effect of tone is isolated (holding the state of embossing and dome constant across comparisons), operators selected keypads with a tone more often than keypads without a tone (except when embossing and dome were both present) [keypad 5 < keypad 1, keypad 7 < keypad 3, keypad 6 < keypad 2, keypad 4 = keypad 8].

With tone held constant, operators showed no preference between keypads with only embossing and keypads with only domes (keypad 2 = keypad 3, keypad 6 = keypad 7). If one keypad had two or three more features than another keypad (regardless of the type of features), the keypad with more features was preferred, $p < .0001$ (keypad 8 < keypad 1, keypad 7 < keypad 1, keypad 6 < keypad 1, keypad 4 < keypad 1, keypad 8 < keypad 2, keypad 8 < keypad 5, keypad 8 < keypad 3).

Figure 4. Median ranks of the paired comparison data as a function of: (a) dome and embossing with no tone, (b) dome and embossing with tone.

Figure 5. Median ranks of the paired comparison data as a function of dome and tone with no embossing, (b) dome and tone with embossing.

In short, dome and tone appeared to have the largest effect on operator's paired comparison scores.

Comparative rating scales. Tone-off and tone-on Comparative Rating Scale results were analyzed separately using 2-Way Friedman Rank Sums Tests. Tables 3 and 4 show the keypad conditions compared and their respective median ranks.

When tone was turned off for the four keypad conditions, a significant difference was found, $\chi^2 (3) = 81, p < .001$. At a probability error rate of .01, a distribution-free multiple comparison test based on the Friedman rank sums was used to determine which keypads were preferred. Table 3 shows that all but two comparisons were found to be significant.

Figure 6 shows that when the effect of dome is isolated (holding the state of embossing constant across comparisons), operators rated the keypads with domes higher than keypads without domes (keypad 4 < keypad 2, keypad 3 < keypad 1). When domes were not present, operators rated the keypad with embossing (keypad 2) higher than the keypad without embossing (keypad 1). When domes were present, no significant difference was found between embossed keys (keypad 4) and non-embossed keys (keypad 3). The keypad with only domes (keypad 3) and the keypad with only embossing (keypad 2) were rated equally. Clearly, the keypad with embossing and domes (keypad 4) was rated higher than the no-embossing, no-domes condition (keypad 1), $p < .0001$.

A separate 2-Way Friedman Rank Sums Test was applied to the tone-on subject data. When tone was turned on for the four keypad conditions, a significant difference was found, $\chi^2 (3) = 53, p < .001$. At a probability error rate of .01, a distribution-free multiple comparison

Table 3
Comparative Rating Scale Data with Tone Off

	Keypad condition			
	Keypad 1 no tone no dome no embossing	Keypad 2 no tone no dome embossing	Keypad 3 no tone dome no embossing	Keypad 4 no tone dome embossing
Median rank*	4	3	2	1
Non-significant differences				

* 1=most preferred 4=least preferred

Table 4
Comparative Rating Scale Data with Tone On

	Keypad condition			
	Keypad 5 tone no dome no embossing	Keypad 7 tone dome no embossing	Keypad 6 tone no dome embossing	Keypad 8 tone dome embossing
Median rank*	4	3	2	2
Non-significant differences				

* 1=most preferred 4=least preferred

Figure 6. Median ranks of the comparative rating scale data as a function of: (a) dome and embossing with no tone, (b) dome and embossing with tone.

test based on the Friedman rank sums was used to determine which keypads were preferred. Table 4 shows the comparisons that were not found to be significant.

Figure 6 shows that when keys were not embossed, operators rated the keypad with domes (keypad 7) higher than the keypad without domes (keypad 5). When keys were embossed, however, keys with domes (keypad 8) and keys without domes (keypad 6) were rated equally. When operators used keypads that had no domes, they ranked embossed keys (keypad 6) higher than non-embossed keys (keypad 5). When operators used pads with domes, however, embossed keys (keypad 7) and non-embossed keys (keypad 8) were rated equally. The keypads with only domes (keypad 7) and the keypad with only embossing (keypad 6) were also rated equally. Clearly, the keypad with embossing and domes (keypad 8) was preferred over the no-embossing, no-domes condition (keypad 1), $p < .0001$. In short, the comparative rating scales showed that the preference for embossing and domes was not significantly different regardless of the state of tone.

Keying time. The time taken to enter each sequence was extracted from the keying time data (from depression of the first # in the sequence to depression of the last # in the sequence). Keying times for each subject's 50 correctly keyed sequences were added to obtain a total keying time score. An $F_{\max}$ test was run on this data and was not found to be significant; and observation of the data's distribution showed that a transformation was not needed before analysis. Total keying times were analyzed with a 2 x 2 x 2 Analysis of Variance (tone x dome x embossing) [Barker & Barker, 1981].

From Table 5 it can be seen that the main effect of dome was significant, $F(1,40) = 5.22, p < .05$. An η^2 test showed that 11% of the variability could be accounted for by the effect of dome. Operators keyed the 50 sequences faster on keypads with domes ($M_{\text{domes}} = 116.978 \text{ sec}$) than keypads without domes ($M_{\text{no domes}} = 120.425 \text{ sec}$). No other comparisons were found to be significant.

Keying errors. The number of sequences that were cleared or had errors of omission or commission were extracted from the data. Only errors of omission occurred frequently enough to be analyzed. The number of sequences that included one or more errors of omission were tallied, ranked and analyzed with a one-way, distribution-free test (Kruskal-Wallis, Hollander & Wolfe, 1973). The data did not meet the assumptions for a parametric analysis, i.e., the data were not normally distributed. Table 6 shows the eight keypad conditions compared along with their respective median ranks.

A significant difference was found between keypad conditions, $\chi^2(7) = 27.41, p < .001$. At a probability error rate of .01, a distribution-free multiple comparison test based on Kruskal-Wallis rank sums was used to determine how the keypad conditions compared with one another. Table 6 shows the non-significant differences.

Figure 7 shows that when the effect of tone is isolated (holding the state of dome and embossing constant across comparisons), fewer errors of omission were made on keypads with a tone than keypads without a tone (keypad 5 < keypad 1, keypad 7 < keypad 3, keypad 6 < keypad 2 and keypad 8 < keypad 4). Figure 7 shows that when the effect of domes is isolated (holding the state of embossing and tone constant across

Table 5
Analysis of Variance
Total Keying Time Data

Source of Variance	SS	df	MS	F	Eta ²
Tone (T)	142.13	1	142.13	.44	
Dome (D)	1676.63	1	1676.63	5.22*	11%
Embossing (E)	71.75	1	71.75	.22	
T x D	256.13	1	256.13	.80	
T x E	378.25	1	378.25	1.18	
D x E	43.13	1	43.13	.13	
T x D x E	455.50	1	455.5	1.42	
Error	12854.10	40	321.35		
Total	15877.60	47			

* $p < .05$.

Table 6
Omission Error Data

	Keypad condition							
	Keypad 1 no tone no dome no emboss	Keypad 2 no tone no dome emboss	Keypad 4 no tone dome emboss	Keypad 3 no tone dome no emboss	Keypad 5 tone no dome no emboss	Keypad 6 tone no dome emboss	Keypad 7 tone dome no emboss	Keypad 8 tone dome emboss
Total number of sequences with omissions	89	33	8	9	11	1	1	0
Median rank	42	39.5	31.75	28	20	12	12	12
Non-significant differences								

Figure 7. Median ranks of the omission error data as a function of: (a) dome and tone with no embossing, (b) dome and tone with embossing.

comparisons), operators made less errors of omission on keypads with domes than keypads without domes (except when tone and embossing were both present) [keypad 3 < keypad 1, keypad 4 < keypad 2, keypad 7 < keypad 5, keypad 6 = keypad 8]. Figure 8 also shows that embossing made a difference in omission error only when tone was on and no domes were present (keypad 6 < keypad 5, keypad 1 = keypad 2, keypad 3 = keypad 4, keypad 7 = keypad 8).

If one keypad had two or three more features than another keypad (regardless of the type of features), the keypad with more features had fewer errors of omission, $p < .0001$ (keypad 8 < keypad 1, keypad 7 < keypad 1, keypad 6 < keypad 1, keypad 4 < keypad 1, keypad 8 < keypad 2, keypad 8 < keypad 5, keypad 8 < keypad 3).

Semantic differential and 1-10 rating scales. An SPSS Principle-Component Analysis showed that the semantic differential and 1-10 rating scales were predominantly measuring the same parameter (the first component accounted for 65% of the variance). As a result, all the rating scales were added together to create one factor of "keypad acceptability". An SPSS Analysis of Variance was used to analyze the data.

From Table 7 it can be seen that the main effect of embossing was significant $F(1,40) = 9.29$, $p < .005$. An η^2 test showed that 17% of the variability could be accounted for by the effect of embossed key edges. Operators gave keys with embossing better acceptability ratings ($M_{\text{embossing}} = 31.17$) than keys without embossing ($M_{\text{no embossing}} = 45.87$) [ratings could vary from 12 to 87]. On the 7-point semantic differential scales and the 1-10 rating scale, the embossed keys were rated approximately 1.2 points better than the non-embossed keys (Mean

Figure 8. Median ranks of the omission error data as a function of: (a) dome and embossing with no tone, (b) dome and embossing with tone.

Table 7
Analysis of Variance
Keypad Acceptability Ratings
(Combined Semantic Differential
and 1-10 Rating Scales)

Source of Variance	SS	df	MS	F	Eta ²
Tone (T)	35.02	1	35.02	.13	
Dome (D)	682.52	1	682.52	2.44	
Embossing (E)	2596.02	1	2596.02	9.29*	17%
T x D	15.19	1	15.19	.05	
T x E	346.69	1	346.69	1.24	
D x E	82.69	1	82.69	.30	
T x D x E	22.69	1	22.69	.08	
Within cells	11177.17	40	279.43		
Total	14957.99	47			

*p < .005.

rating per scale for the non-embossed keys = 3.8; Mean rating per scale for the embossed keys = 2.6). No other comparisons were found to be significant.

Correlations between performance and preference measures. Spearman Rank-Order Correlations ("rho") were obtained for all pairs of dependent measures. A significant correlation of .90 ($p < .01$) was found between paired comparison rankings and omission error scores across the eight keypads. No other correlations were found to be significant (see Table 8).

Discussion

The task of key pressing can be decomposed into two actions, locating the key and activating the key. Controls with characteristics that allow the operator to easily locate a key and detect when the key has been activated should be associated with better performance. The better the cues defining the key, the less time proper finger placement should take. Keys that can be easily discriminated from each other should yield faster keying times as well as fewer inadvertent activation errors. Feedback that provides a clear cue that activation has occurred should lead to fewer errors of omission.

Providing cues for proper finger placement is relatively easy with push-buttons. The physical separation of keys and keycap size and shape provide both visual and tactile key discrimination cues. In contrast, key separation on a completely flat panel of membrane keys is provided solely by keycap graphics. There are no tactile cues which separate such keys.

Studies of push-buttons have shown that the form of kinesthetic feedback provided by key displacement is an important determinant of keying speed and error rates (Alden et al., 1972). The literature also shows

Table 8
Spearman Rho Correlations between
Performance and Preference Measures

	Paired Comparisons	Keying Time	Semantic Differentials
Omission Errors	.8988*	.6131	.4226
Semantic Differentials	.7143	.0714	
Keying Time	.5238		

* $p < .01$.

that providing additional feedback (visual, auditory, kinesthetic) does not appear to affect keying performance or operator preference during typing and data-entry tasks (Alden et al., 1972; Pollard & Cooper, 1979). Unlike push-buttons, membrane keys have virtually no displacement upon activation. This leads to the hypothesis that the absence of kinesthetic feedback on membrane keys would lead to higher error rates and lower preference scores.

Membrane keys can be enhanced with features that provide key separation cues and activation feedback. Enhancements to membrane keys include embossed key edges, key locator overlays, lights, clicks, tones, and metal domes.

Domed membrane keys can provide, to some extent, the kinesthetic feedback of a push-button. Tone can also provide activation feedback. Embossed key edges can provide visual and tactile finger placement cues.

The purpose of this experiment was to determine the effects of adding different types of tactile, visual, auditory, and kinesthetic cues to a flat and silent membrane panel. More specifically, the effects of the addition of metal domes, embossed key edges, and a 1000 Hz tone on preference and performance measures were examined. Of particular interest were the effects of different combinations of cues on keying performance and preference.

It is clear from the findings of this study that key discrimination provided by embossed key edges and feedback provided by metal domes and auditory tones had a significant effect on keying performance and operator ratings of membrane keypads. [A summary of the findings of this study is provided in Table 9.]

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

FEEDBACK AND KEY DISCRIMINATION
ON MEMBRANE KEYPADS

A thesis submitted in partial satisfaction of the
requirements for the degree of Master of Arts in

Psychology

by

Cynthia Jean Roe

January 1984

Table 9
Summary of the Results

Paired Comparisons

Comparative Rating Scales

Omission Errors

*Lines drawn below icons represent non-significant differences

Keying Time

Semantic Differential Scales

In contrast to the results reported for push-buttons (Alden et al., 1972; Pollard & Cooper, 1979), the current study found that the addition of auditory feedback on membrane keys yielded significantly better paired comparison rankings and significantly fewer omission errors when combined with domes and/or embossing. One could speculate that if the amount of kinesthetic feedback is adequate (as with push-buttons), the addition of auditory feedback provides no further benefit. However, when kinesthetic feedback is not adequate (as with membrane switches), auditory feedback can provide a needed activation cue to the operator. This speculation is borne out by the paired comparison and omission error data, i.e., tone and dome (keypad 7) was better than dome alone (keypad 3).

Paired comparison and omission error data also showed that there was no significant difference between a tone/embossing combination (providing auditory and tactile cues) and a tone/dome combination (providing auditory and kinesthetic cues). The conclusion is that the pairing of auditory feedback with tactile and/or kinesthetic feedback yielded the best paired comparison and omission error scores. Given the similarity between the paired comparison and omission error results, it is not surprising to find a significant correlation of .90 between these two measures.

The results obtained from the comparative rating scales and paired comparisons showed that the preferences for embossed edges and domes were not significantly different regardless of pairing with tone (keypad 2 = keypad 3, keypad 6 = keypad 7). The omission error data, however, showed that when the tone was not present, domed keys showed fewer errors than embossed keys. More specifically, the median error score for the embossing-only keypad was 3.5. The median error score for the dome-only

keypad was 1.5. In both cases, the median reduces to zero when auditory feedback was included.

Semantic differential scale data obtained after the keying tasks showed that subjects significantly preferred embossed key edges. On a 7-point scale embossed keys were rated approximately 1.2 points better than the non-embossed keys. Given the general lack of sensitivity of semantic differential scales, the results favoring embossing should be taken in the context of the results obtained from the paired comparison, comparative ratings scale and omission error data. These results showed that embossing paired with a tone or embossing paired with a tone and a dome yielded high preference scores and low error scores.

The results of the analyses performed on the keying time data showed a significant effect of dome versus no dome. Given that this study focused on infrequently used keys (not keys designed for rapid data-entry), the average difference of 0.017 seconds (key-to-key activation time) across the dome and no dome conditions is of no practical consequence.

While few errors of commission were made, examination of the commission error data showed that the membrane keys used in this study had a tendency to bounce (resulting in erroneous recordings of multiple activations from a single key stroke). Examination of the commission error data revealed that inter-activation times were as short as 8 ms. Pollard and Cooper (1979) also reported inter-activation times ranging between 0 and 50 ms. Pollard and Cooper attributed these times to the tremor of subjects' fingers. The effects of key bouncing can be eliminated by electronically rejecting all inter-activation times that are less than some chosen minimum. Studies need to be done to determine a minimum

time that would lock out activations caused by key bouncing but not lock out rapid, intentional keystrokes.

Limits to generality of results. The results of this study should only be applied to situations where membrane keys are infrequently used. Even though the experimental keying task was relatively short, subjects reported that the task was fatiguing. The overall median semantic differential score on the hard to push(1)/easy to push(7) scale was 2. The overall median semantic differential score on the tiring (1)/restful (7) scale was 1. Given these low ratings after a keying task that lasted approximately two minutes, designers considering the use of membrane keys should seriously take into account frequency of key use and keying task duration.

In addition, the applicability of the results is limited to the characteristics of the different types of membrane keys tested (e.g., keys 0.75 inches apart with an 8 ounce operating force, domes with 0.016 inch travel). Variations in these characteristics or the addition of other key enhancements (such as LEDs) very possibly could change the pattern of results. Environmental conditions may also affect the pattern of results. For example, high ambient acoustic noise might preclude the use of auditory feedback.

Summary. The results of this study showed that the feedback and cues provided by a tone combined with embossed key edges and/or metal domes enhanced performance and increased preference scores on membrane keys. This result contradicts the results of studies utilizing push-buttons. For the membrane keys studied, tone proved to be a significant source of activation feedback. One possible interpretation is that embossed

edges and metal domes do not provide the same quality of kinesthetic and tactile feedback associated with push-button keys.

Given the varied uses of membrane keys on both office and consumer products, and given the number of different membrane key enhancements available, further research is required before a valid set of design guidelines can be formed. The results of this study suggest that both performance and preference data are needed to adequately evaluate the acceptability of different membrane key designs.

Keying time data from this study indicated that operators could key faster on keypads with domes. Omission error and preference data, however, showed that keypads with auditory feedback (tone) along with tactile and/or kinesthetic feedback (embossed edges and/or domes) yielded the best results. Future research designed to develop guidelines needs to include both preference and performance measures. Data from each measure need to be weighed according to the intended use of a particular design.

References

- Alden, D. G., Daniels, R. W., & Kanarick, A. F. (1972). Keyboard design and operation: a review of the major issues. Human Factors, 14(4), 275-293.
- Barker, A. M., & Barker, T. B. (1981). ANOVA [Computer program]. Dynacomp.
- Deininger, R. L. (1960). Desirable push-button characteristics. IRE transactions, 1, 24-30.
- Hollander, M., & Wolfe, D. A. (1973). Nonparametric statistical methods. New York: John Wiley & Sons.
- Pollard, D., & Cooper, M. B. (1979). The effect of feedback on keying performance. Applied Ergonomics, 10(4), 194-200.
- Seibel, R. (1972). Data entry devices and procedures. In H. Van Cott & R. G. Kinkade (Eds.), Human engineering guide to equipment design (pp. 311-344). Washington, DC: McGraw-Hill.
- Spencer, T. (1981). Bell Systems. Personal communications.
- Thomas, E. (1982). K. B. Denver. Personal communications.
- Woodson, W. E. (1981). Human factors design handbook. New York: McGraw-Hill.

Appendix 1

KEYPAD STUDY INSTRUCTIONS

PART I

I have asked you here to participate in an evaluation of several membrane keypads with "touch sensitive" switches. I need to know how well certain types of membrane switches perform and which type of switch you would prefer given the choice.

I am going to conduct this evaluation in two parts. During this first part, I will have you enter a few numbers on two different keypads and ask you which of the two you prefer.

A light will come on above the keypad you are to use. Please do not use any keypad unless its light is on. Let me know if you'd like to try a keypad a second time before you make your choice.

You will be asked to make several such comparisons. Do you have any questions?

Appendix 2

KEYPAD STUDY INSTRUCTIONS

PART II

Now you will be rating all four keypads on several "comparative rating scales". The following example shows you how these comparative scales work:

Example

If I asked you how you like the taste of Bananas, Oranges, Pears and Apples, you might respond like this:

dislike the O taste B P A like the taste

This scale shows how you comparatively feel about each fruit's taste. You like Apples the best and you clearly dislike the taste of Oranges and Bananas.

Notice that you can place your ratings anywhere on the scale to reflect exactly how you feel about each item. If you feel the same about two or more items, you can put them at the same place on the scale (notice how Oranges and Bananas are equally rated on the scale above).

I would like you to rate the four keypads on several of these comparative rating scales. I will have you rate the keypads on several scales with all the beepers turned on and on several others with the beepers turned off.

All four red lights will be turned on so that you can use any of the keypads while you're making your comparisons. Use the symbols above each keypad (Δ * $\circ$ $\square$) to mark your ratings on each scale.

Do you have any questions?

Appendix 3

Operator # _____

COMPARATIVE RATING SCALE

Draw all four keypad symbols on the scale below according to how you rate each keypad with all beepers turned on:

BEST / _____ / WORST

Appendix 3 (Continued)

Operator # _____

COMPARATIVE RATING SCALE

Draw all four keypad symbols on the scale below according to how you rate each keypad with all beepers turned off:

BEST / _____ / WORST

Appendix 4
Keystroke Combinations
Arranged by
Direction-of-Movement & Distance

<u>Movement</u>		<u>Direction</u>	<u>Quantity</u>	<u>Key Combinations</u>
<u>Vertical</u>	<u>Horizontal</u>			
0	1	W	9	87 C3 21 65 E9 32 D6 54 98
0	1	E	9	12 23 3C 78 89 45 56 6D 9E
0	2	W	7	C2 D5 E8 31 64 97 F0
0	2	E	7	2C 5D 8E 0F 13 46 79
0	3	W	3	C1 D4 E7
0	3	E	3	1C 4D 7E
1	0	N	7	96 63 74 41 08 85 52
1	0	S	7	14 47 25 58 80 36 69
1	1	SE	8	15 26 3D 48 59 6E 70 9F
1	1	NE	7	42 53 09 6C 75 86 9D
1	1	SW	7	D9 90 24 35 C6 57 68
1	1	NW	8	51 62 D3 07 F9 84 95 E6
1	2	SE	5	16 2D 49 5E 8F
1	2	NE	5	0E 76 8D 43 5C
1	2	SW	5	34 C5 67 D8 E0
1	2	NW	5	F8 94 E5 61 D2
1	3	SE	3	1D 4E 7F
1	3	NE	2	7D 4C
1	3	SW	2	C4 D7
1	3	NW	3	F7 E4 D1
2	0	N	4	05 71 82 93
2	0	S	4	17 28 39 50
2	1	SE	5	18 29 3E 40 6F
2	1	NE	4	06 72 83 9C
2	1	SW	4	27 38 C9 60
2	1	NW	5	04 F6 81 92 E3
2	2	SE	3	19 2E 5F
2	2	NE	3	0D 73 8C
2	2	SW	3	37 C8 D0
2	2	NW	3	F5 91 E2
2	3	SE	2	1E 4F

Appendix 4 (Continued)

<u>Movement</u>		<u>Direction</u>	<u>Quantity</u>	<u>Key Combinations</u>
<u>Vertical</u>	<u>Horizontal</u>			
2	3	NE	1	7C
2	3	SW	1	C7
2	3	NW	2	F4 E1
3	0	N	1	02
3	0	S	1	20
3	1	SE	2	10 3F
3	1	NE	1	03
3	1	SW	1	30
3	1	NW	2	01 F3
3	2	SE	1	2F
3	2	NE	1	0C
3	2	SW	1	C0
3	2	NW	1	F2
3	3	SE	1	1F
3	3	NE	0	
3	3	SW	0	
3	3	NW	1	F1
0	0	00	10	11 22 33 44 55 66 77 88 99 00
			<u>180</u>	Total

Appendix 5

Stimulus Sequences

The following sequences include every possible key-to-key combination on the experimental 16-key keypads. Combinations do not include the "A" (ENTER) & "B" (CLEAR) keys.

1. 90 D55	26. 78 C13
2. 72 F45	27. 56 E09
3. 11 D43	28. 54 D63
4. 42 C02	29. 12 E29
5. 37 C25	30. 28 D30
6. 98 E47	31. 69 D80
7. 24 F68	32. 73 F14
8. 75 F04	33. 18 F66
9. 41 E67	34. 85 E08
10. 61 C89	35. 97 D38
11. 23 E82	36. 79 E10
12. 22 D15	37. 49 F27
13. 26 F17	38. 81 F87
14. 65 D76	39. 00 D96
15. 03 D20	40. 05 C88
16. 39 C62	41. 70 F21
17. 40 C31	42. 93 C71
18. 36 C58	43. 34 D01
19. 60 E51	44. 16 F33
20. 64 C48	45. 32 E74
21. 94 E19	46. 59 C92
22. 46 D99	47. 83 F86
23. 07 F52	48. 53 F91
24. 57 E35	49. 84 E95
25. 50 F77	50. 44 C06

Appendix 7

Operator # _____

File # _____

Condition # _____

KEYPAD EVALUATION FORM

Mark an "X" on each scale in the space that best reflects your impression about the keypad you just used:

hard to push keys	/ / / / / / / /	easy to push keys
annoying	/ / / / / / / /	pleasant
strange	/ / / / / / / /	familiar
slow to respond	/ / / / / / / /	quick to respond
tiring	/ / / / / / / /	restful
undesirable	/ / / / / / / /	desirable
sluggish	/ / / / / / / /	lively
frustrating	/ / / / / / / /	enjoyable
hard to locate keys	/ / / / / / / /	easy to locate keys

Overall, what is your impression of this keypad:

worst	/ / / / / / / /	best
unacceptable	/ / / / / / / /	acceptable

On a scale of 1 to 10 (where 10 is the best possible keypad and 1 is the worst possible keypad), how would you rate this keypad? _____

Please use this space for any additional comments:

Appendix 8

Operator # _____

KEYPAD STUDY
BACKGROUND QUESTIONNAIRE

Age:

_____ - 20
 _____ 21 - 30
 _____ 31 - 40
 _____ 41 - 50
 _____ 51 - 60
 _____ 60+

Education (highest year completed): _____

Years typing experience:

_____ 0 - 5
 _____ 6 - 10
 _____ 11 - 15
 _____ 16+

Approximate typing speed:

_____ 0 - 40
 _____ 41 - 50
 _____ 51 - 60
 _____ 61 - 70
 _____ 71 - 80
 _____ 80+

Check products that you have used:

_____ Electronic typewriter
 _____ Word processor
 _____ Computer data entry device (keyboard & VDT terminal, keypunch, etc.)
 _____ Adding machine
 _____ Calculator
 _____ Cash register

Can you key numbers on a 10-key numeric pad without looking
down at the keys? (circle one) YES NO

Several products on the market (such as microwave ovens, Xerox electronic typewriters, washing machines, etc.) are using "touch sensitive" keys (flat keys sensitive to touch). Have you ever used such "touch sensitive" key? (circle one) YES NO