THE OPTIMAL KEYBOARD ANGLE FOR MULTIPLE-FINGER TAPPING

by

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INTRODUCTION

This study was designed to investigate multiple-finger tapping performance as a function of the keyboard angle. The keyboard angle, as defined in this study, is the angle formed by the plane of the tapping surface and a horizontal plane (see Plate I). Tapping performance was measured in terms of speed of tapping, the number of errors and an index of the decrease in rate of tapping throughout each test trial from which amount of fatigue was inferred.

A review of the literature indicates that previous tapping studies used only one finger tapping. Chapanis, et. al. (3) suggest that the "normal" horizontal keyboard, which requires vertical tapping movements, is not the optimal type of keyboard for one finger tapping when speed of tapping is used as the measure of performance. They state that tapping is considerably faster on a vertical keyboard which requires horizontal tapping. In a related area, improvements have been suggested for the typewriter keyboard. Biegel (1) modified the typewriter keyboard so that the rows of the keys were curved rather then straight. He attempted to shape the keyboard so that it would be the same shape as the typists hands in a natural position. Other typewriter keyboard changes were confined to changing the letters to different keys.

It is hypothesized that multiple-finger tapping performance will vary as a function of the keyboard angle. Also, it is assumed that there will be a separate function for rate, errors and fatigue but that these functions will be similar.

With the many office machines that require multiple-finger tapping, it appears that additional information about multiple-finger tapping would be highly desirable. Without additional information it will be impossible to design the most efficient keyboard for these machines. A keyboard designed for mech-

PLATE I

Fig. 1

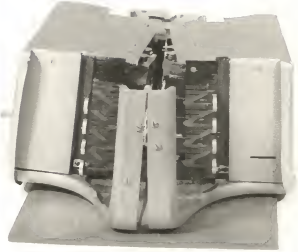

Fig. 2

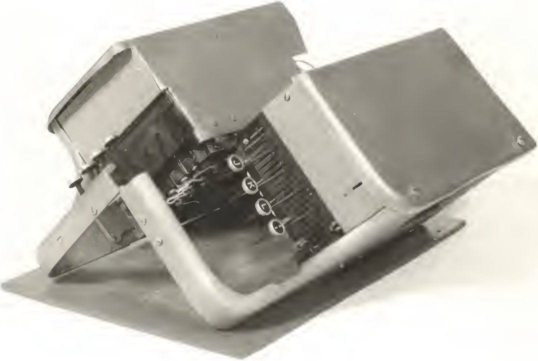

Fig. 3

anical efficiency may be a poor machine if certain human factors are not considered.

The implications drawn from the results of this study have their greatest meaning for typing situations. With the gradual shift to electric typewriters, it might be possible to implement, at a small cost to both producer and consumer, a design change which would have beneficial results. The equipment and task used in this study were selected so that the results might indicate a keyboard design that would produce improved typing performance.

MATERIAL AND METHOD

Tapping Keyboard and Recorder

The equipment used to record the data was an Esterline Angus 20 pen graphic recorder. The recording paper moved at a speed of 12 inches per minute.

A Woodstock standard typewriter keyboard was modified and used as the tapping keyboard (illustrated in Plate I). With the exception of eight keys, all working parts of the typewriter were removed. The eight keys were "A, S, D, F, J, K, L, and ;". These are the eight keys covered by the typists fingers in the "starting" position using the common method of touch typing. The letters and striking mechanism were removed so that the only key connection was the hinge at the rear of the key. The frame and supports were cut through the center, from front to back, dividing the keyboard into two parts. These parts were hinged together so that the angle between the halves of the keyboard could be adjusted to any angle.

A micro-switch was placed under each key and wired in the normally open position. Each switch was adjusted so that the keys had the following stroke lengths: "A and ;" - 4/16th inch, "S and L" - 5/16th inch, "D and K" - 6/16th inch, and "F and J" - 7/16th inch. Keys "A and ;" were depressed by the little fingers, "S and L" were depressed by the ring fingers, "D and K" were depressed by the middle fingers and "F and J" were depressed by the index fingers. At two-thirds of the stroke each switch would change to the closed position. Four ounces of pressure were required to depress all keys.

The keyboard was further modified so that it was possible to set the keyboard at five specific angles. These angles were 0, 22, 44, 66, and 88 degrees from the normal horizontal position. Three of these angle positions are shown in Plate I.

Subjects

Five male subjects from a general psychology class were used. The subjects were non-typists. All subjects were paid for their participation in the experiment.

Procedure

The performance of each subject was measured for 20 consecutive days. Each day was called a session and included a 3 minute test at each of the five angles. The sessions were combined into four blocks of five successive sessions each. During the first session the following instructions were read to all subjects:

> As you will note, the apparatus on the table directly in front of you is in some respects similar to a typewriter. There are four keys for each hand.
>
> When the test begins I will give the following instructions: Alternate both fingers and hands. Start with the little finger on your left hand and then the little finger on your right hand, then

ring left, ring right, middle left, middle right, index left, index right, little left, little right, etc.

Pressing two keys at the same time and failing to alternate with either fingers or hands will be scored as errors. If you make an error start to alternate again on your next tap. If you become confused you may start again with your left little finger. Remember that your errors stop as soon as you start to alternate in the proper sequence.

You may place your fingers on the keys and adjust your chair so that it feels comfortable.

Do you have any questions?

When I say "start", tap as fast and accurately as possible.

On the first day each subject had a one minute practice trial in each of the five angles used for the experiment. The angles were arranged in a 5 x 5 latin square. A different sequence was used for each subject. Each subject received the same order for his practice and his test. The test consisted of three minutes of continuous tapping in each of the five angles. There was a two minute rest period between each position and a two minute rest period between the practice and the first test session.

For the second session, each subject was moved one row down on the latin square so that he received a new sequence. He was given a two minute warmup in the position that he was to receive first in the test. This was followed by a two minute rest and then a test in each of the five keyboard positions. In all following sessions the subjects were rotated and tested in this manner.

After the final session the subjects were questioned (see appendix for a list of the questions) about there performance throughout the 20 sessions.

Each subject tapped approximately 3 minutes and 5 seconds in each position. Time intervals for the test trials were determined by measuring nine inches on the recording tape for each 45 second time unit, or a total of 36 inches for each 3 minute test period. The time intervals were measured from the first response, so that it was possible to time the test exactly by measuring 36 inches on the tape.

Three indices of performance were obtained from the paper recording tape. The rate of tapping was scored by counting the total number of taps on 36 inches of the tape. The measurement started on the first response of a 3 minute test trial. If the subject pressed two or more keys at the same time it was scored as one tap.

An error score was also abtained. One error was scored each time two or more keys were depressed at the same time. An error was also scored when the subject failed to alternate either his fingers or his hands. If during the test trial the subjects started to alternate from right to left instead of left to right as the instructions specified, it was scored as one error for the change. The taps made during the right-left alternation were not scored as errors as long as the subjects alternated with both hands and fingers. The reason for encouraging the left-right alternation was simply to facilitate scoring.

After the first five sessions the subjects made very few errors. For this reason, errors were scored for Block I only.

Fatigue was inferred from a general decrease in the number of taps over four equal units of time for the three minute test trials.

After the first five sessions there was only a slight decrement in performance, so the fatigue scores were obtained for Block I only.

Design

The experimental design was basically a five by five latin square. The same latin square was used each day for 20 days. In other words, the latin square was replicated 20 times by using the same five subjects for all of the replications. The design is illustrated in figure 1.

Each day was called a session and the sessions were combined into four blocks of five sessions each.

The columns of the latin square were ordinal positions, the rows were sequences or subjects and the latin letters were keyboard angles. The latin square was a systematic (cross-over) latin square. A particular treatment was always preceeded and followed by the same two treatments.

On the first day the subjects were assigned to the five different sequences in the order that they came to the experiment. On the next four days all subjects were given a different sequence each day. The subjects were shifted one row down on the latin square each day. No subject received the same sequence twice within any block but all subjects received each sequence four times during the 20 sessions.

The treatments were assigned to the latin letters in a random manner. Each treatment was given a number from one to five. The order that these numbers appeared in a table of random numbers determined the assignment of the treatments to the latin letters.

SESSION 1	Ordinal Position	I	II	III	IV	V
	R 1	B	A	E	C	D
Seq.	G 2	A	E	C	D	B
&	W 3	E	C	D	B	A
Subj.	H 4	C	D	B	A	E
	D 5	D	B	A	E	C

SESSION 2	Ordinal Position	I	II	III	IV	V
	D 1	B	A	E	C	D
Seq.	R 2	A	E	C	D	B
&	G 3	E	C	D	B	A ....
Subj.	W 4	C	D	B	A	E
	H 5	D	B	A	E	C

SESSION 20	Ordinal Position	I	II	III	IV	V
	G 1	B	A	E	C	D
Seq.	W 2	A	E	C	D	B
&	H 3	E	C	D	B	A
Subj.	D 4	C	D	B	A	E
	R 5	D	B	A	E	C

Ordinal Positions: I, II, III, IV and V.
Sequences: 1, 2, 3, 4, and 5.
Subjects: R, G, W, H and D.
Angles: A=0, B=22, C=44, D=66 and E=88.

Figure 1. Experimental design.

RESULTS

Tapping Speed

Tables 1 and 2 summarize the data using tapping speed as the measure of performance. Table 1 is an analysis of variance summary for the speed data of Block I. Both the angles and the sequences are significant beyond the .05 level of significance. From figure 2 it is obvious that tapping in the zero degree position (horizontal keyboard) is slower than tapping at the other angles. The 66 degree angle produces the best performance with the 44 degree and 88 degree positions ranking second and third, respectively. The Student-Newman-Keuls (7,9) gap test shows that there are no significant differences between any two angle means.[1] In other words, the significant angle difference is due to the trend from poor performance in some angles to good performance in other angles. It is not the result of one or two of the

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1 The Student-Newman-Keuls gap test is used throughout this study to test differences between the various pairs of means.

angles being quite different from the others.

Table 1. Summary of analysis of variance for block I: speed of tapping.

Source of variance	df	SS	MS	F
Angles	4	829.04#	207.26	4.81**
Sequences	4	436	109.00	2.53*
Ordinal Position	4	345	86.25	2.00 ns
Variability due to subjects and/or squares				
Square Uniqueness	12	449	37.42	
Individuals within seq.	20	68,346	3,417.30	
Replication	80[1]	3,445	43.06	
Total	123[1]			

* $p < .05$
**$p < .01$
\# Sum of squares corrected for bias for estimating one cell.
[1] Loss of one degree of freedom for estimating the score in one cell.

Each unit in this data represents eight taps. Thus to compare the mean performance of the different angles, the units should be multiplied by eight. A difference of six units in figure 2 would indicate a mean difference of 48

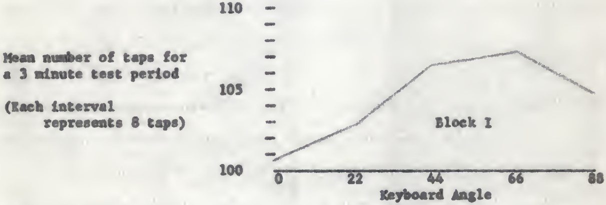

Figure 2. Speed of tapping as a function of the keyboard angle.

taps in a three minute period or a difference of 16 taps in a one minute period. Interpreting the results in the proper units gives a more realistic picture of the difference between the angles.

The results of one 3 minute test session for one subject were not obtained during the second session. The score for this cell was estimated by the procedure outlined in Snedecor (8).

Table 2. Summary of analysis of variance for block IV: speed of tapping.

Source of variance	df	SS	MS	F
Angles	4	1,396	374.00	7.87**
Sequences	4	690	172.50	3.63**
Ordinal Position	4	90	22.50	.47 ns
Variability due to subjects and/or squares				
Square Uniqueness	12	676	56.33	
Individuals within seq.	20	15,332	766.60	
Replication	81	3,848	47.51	
Total	124			

** $P < .01$

The speed of tapping data for Block IV are summarized in table 2. The F ratio is significant for both the angles and the sequences.

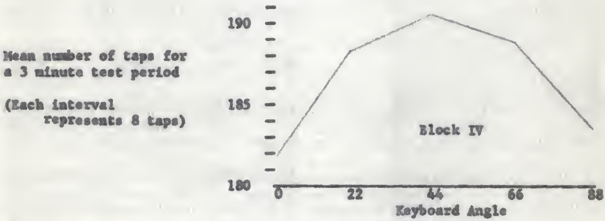

Figure 3. Speed of tapping as a function of the keyboard angle.

Figure 3 shows that the angle that produced the fastest tapping was 44 degrees. It is obvious that there is a shift in the relative difference between the angles from the first to the fourth block. The greatest shift for any position was at the 88 degree angle. Relative performance in this position decreased so that it is almost the same as that at the 0 degree position.

The gap test indicates that no one mean was significantly different from other means.

Errors

Table 3 summarizes the results of the analysis of variance for errors in Block I. The mean sum of squares for the angles resulted in a significant F ratio. The gap test indicated no significant difference between any of the pairs of angle means. The greatest absolute difference between two adjacent means is from the zero degree position to the 22 degree position. The difference here is considerably greater than the differences between other means. Figure 4 is a graphic representation of the differences among the means.

Table 3. Summary of analysis of variance for block I: errors.

Source of variance	df	SS	MS	F
Angles	4	4,594.75#	1,148.68	4.37**
Sequences	4	3,411	852.75	3.25*
Ordinal Position	4	2,056	514.00	1.96 ns
Variability due to subjects and/or squares				
Square Uniqueness	12	2,143	178.58	
Individuals within seq.	20	37,123	1,856.15	
Replication	80[i]	21,003	262.54	
Total	123[i]			

* $P < .05$
**$P < .01$
\# Sum of squares corrected for bias for estimating one cell.
[i] Loss of one degree of freedom for estimating the score in one cell.

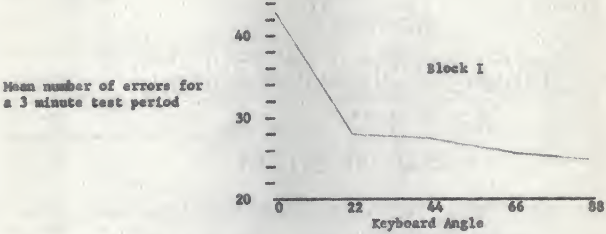

Figure 4. Mean number of errors as a function of the keyboard angle.

Slope

Fatigue was inferred from a general decrease in the number of taps over four equal units of time for the three minute test trials. This decrease in

Table 4. Summary of analysis of variance for block I: slope.

Source of variance	df	SS	MS	F
Angles	4	285.25#	71.30	1.11 ns
Sequences	4	665	166.25	2.58*
Ordinal Position	4	632	158.00	2.47 ns
Variability due to subjects and/or squares				
Square Uniqueness	12	690	57.50	
Individuals within seq.	20	3,243	162.15	
Replication	80[1]	5,123	64.03	
Total	123[1]			

* $P < .05$

\# Sum of squares corrected for bias for estimating one cell.

[1] Loss of one degree of freedom for estimating the score in one cell.

the number of taps was almost a linear function of the four units of time, as indicated by figure 5. Assuming that the relation of the number of taps to these four time units was linear, it was possible to compute the slope or trend of the regression. This slope score gave a direct indication of the

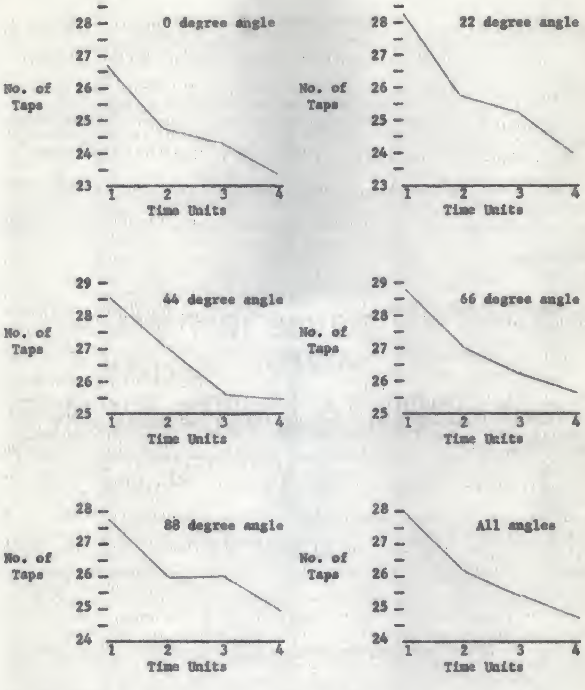

Figure 5. Relation of the mean number of taps to four equal time units (45 seconds each) within each 3 minute test period. The mean number of taps is shown for each keyboard angle and a combination of all the angles. Each interval on the ordinate represents a unit of eight individual taps.

decrement in performance over the four units of time. An estimate of the slope was obtained for each three minute test period.

The analysis for the slope scores is summarized in table 4. The mean sum of squares for the sequences results in a significant F ratio. The analysis of variance indicated no difference among the five angles. The data indicated that there was some fatigue in all positions but that the difference among the angles was not significant.

Effects of Practice

The mean number of taps for each of the 20 sessions is summarized in figure 6. It appears that the performance is closely approaching but has not reached the upper limit of the subjects ability.

Figure 7 illustrates the differential effects of practice for performance at the different angles relative to the zero or "normal" horizontal position. As noted previously, the optimal angle in terms of speed changes from 66 degrees to 44 degrees. The relative performance in the 88 degree position deteriorates considerably from Block I to Block IV.

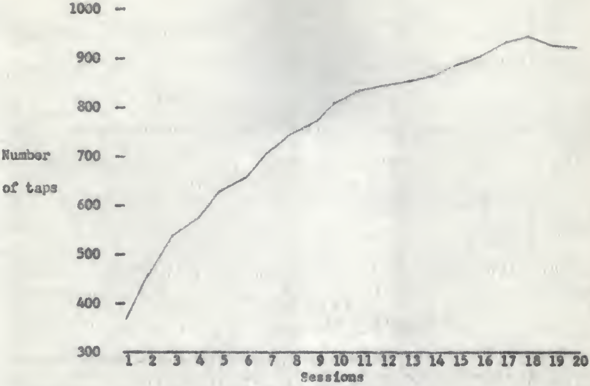

Figure 6. The mean number of taps for the five subjects is plotted as a function of the sessions.

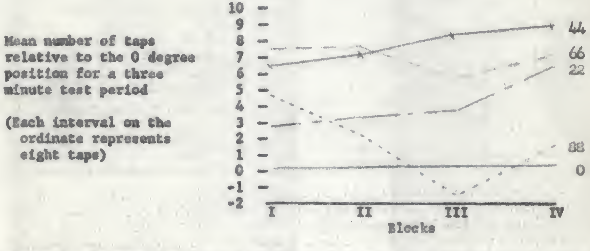

Figure 7. The mean number of taps for each angle is plotted as a function of the blocks. The mean number of taps for each angle is adjusted to a common zero for each block. The taps are adjusted by subtracting the mean number of taps for the zero degree angle from the mean number of taps for all other angles.

DISCUSSION

There is a significant difference among the sequences for all of the indices used. It is significant for the speed of tapping for both Block I and Block IV.

Inspection of the speed of tapping data for Block I indicated that the difference might be due to different rates of learning for the five subjects. Since each subject received each sequence on a different day, the sequence total for Block I is made up of the data of five different subjects on five different days. If the subjects progressed at the same rate for the five sessions, any differences due to subjects would balance so that the sequences would be independent of the difference between the subjects. Inspection of the data indicated that the subjects progressed at different rates. Therefore the sequences would reflect the different rates of learning.

An explanation, similar to the one just used for the Block I speed data, could be used for Block I errors and slope. It could also be used for the speed data of Block IV.

To determine the relation between errors and number of taps, a Pearson Product-moment correlation was computed. A correlation coefficient of +.160 was obtained which is no larger than might be expected by chance. It would appear that speed and errors are two relatively independent measures of performance.

Fatigue was expected to be an important factor in the differences in performance among the angles. The quantitative data show no difference among the angles using the slope score as a measure of fatigue. After the last session, all subjects were asked which angle caused the greatest fatigue during the 20 sessions. All five subjects reported that the zero degree angle produced the greatest fatigue. Some stated that the 22 degree angle caused fatigue but not as great as the zero degree position. Four subjects stated that they worked harder in the 0 degree position. The attitude of the subjects seems to be expressed quite well in an impromptu statement of one of the subjects. After finishing a three minute test in the 0 degree position he said, "I'll swear, this position gets harder each time I do it".

It would appear that there is a definite possibility of a difference in the amount of fatigue generated by the different angles. The measure of fatigue selected for this study may not have been adequate since the subjects seemed to be able to compensate by working harder in certain positions. It seems obvious that fatigue would be reflected, to some degree, in the speed measures. However, it also appears that it would be worthwhile in future studies to provide an adequate measure of fatigue per se.

To obtain a more reliable estimate of differences in fatigue, two methods are suggested. The test period could be extended over a much longer interval of time. This should prevent the subject from working harder in some positions to compensate for fatigue. In addition, electrical potentials could be measured to determine the muscular activity for the different positions.

Practice or learning over the 20 sessions showed two very important trends. First, performance in the 88 degree position became worse, relative speaking, during the 20 sessions. Secondly, the optimal keyboard angle changed from the 66 degree position to the 44 degree position. It appears that future studies in this area should be carried out over an extended period of time so that the effects of practice can be determined.

Although the optimal angle changed during the 20 sessions, the absolute difference between the best and worst positions remained approximately the same. The difference did not increase proportionately with the increase of tapping speed. It would appear that a change of the keyboard angle would produce approximately the same improvement for all individuals regardless of their level of ability.

After the last session the subjects were ask which keyboard angle they would choose if they could have a keyboard angle designed for their use. Three subjects chose the 44 degree angle and two selected the 66 degree angle. It appears that preferences agree quite well with performance for these five subjects.

The results of this experiment indicate that the angle of the keyboard does make a difference in tapping speed and number of errors. The optimal angle for the two indices is not the same, but the difference is small and could probably be reconciled in designing a new keyboard.

The speed of tapping is considered the more important measure of performance. Although the tapping speed is not exactly analogous to typing speed, they seem to be quite closely related. The tapping task used in this study would be similar to typing the same eight letter word for three minutes.

An error, as used in this study, is considered a measure of the ability of the subject to coordinate his hands and fingers and follow a fixed stimulus pattern. Typing stimuli are quite different, but the number of errors still reflect the ability of the subject to coordinate his fingers and make the proper response to each stimulus.

In general, the practical implications of this study need little explanation. The task and equipment are similar to typing and typing equipment. The most significant practical result of the experiment was the relatively poor performance in the 0 degree position compared to the other positions.

In other words, the horizontal keyboard, which closely resembles the keyboard found on typewriters and many other machines, was the keyboard that produced the poorest performance throughout the study. The most general interpretation of the data might indicate that considerable improvement in performance would result in typing and similar activities by re-designing the keyboard. Even though this seems quite plausible, the equipment and the task used in this study would not permit this unqualified generalization to the typing situation.

The results of this study serve as a guide for further research in this area. It appears that further study using typists for subjects and a full keyboard with a typing task would permit more conclusive evidence for the design problem.

SUMMARY

This experiment was designed to study speed of multiple-finger tapping performance as a function of the keyboard angle. It was designed to determine the optimal keyboard angle in terms of tapping speed, number of errors, and fatigue. Tapping speed was considered the most important measure of performance.

Five male general psychology students were used as subjects. They were paid for their participation.

The tapping board was a modified typewriter keyboard which had eight keys. The keyboard was constructed so that the direction of tapping movement could be varied from the normal vertical movements to horizontal movements. Five angles were used: 0 (required normal vertical movements), 22, 44, 66 and 88 (required horizontal movements) degrees.

The task was a simple alternation of both hands and fingers which the subject repeated throughout all test periods.

All subjects received a three minute test session in each angle position every day for 20 days. The order of presentation was balanced by using a 5 x 5 latin square design. Each day was called a session and the sessions were combined into four blocks of five sessions each.

Using speed of tapping as a measure of performance, there was a significant difference among the angles for both Block I and Block IV. In Block I the 66 degree angle produced the fastest tapping while in Block IV the 44 degree angle produced the fastest tapping. Tapping was slowest in the 0 degree angle for both Blocks I and IV. There was a significant difference among the angles for Block I when errors were used as a measure of performance. The greatest number of errors were committed in the zero degree angle and the least number of errors were made in the 88 degree angle. There was little difference among the 22, 44, 66 and 88 degree angles in number of errors. There was no significant difference among the angles when a slope measure, indicative of performance decrement within trials, was used as an index of fatigue.

Both the performance of the subjects and their verbal statements indicated that the optimal keyboard angle would be either the 44 or the 66 degree position. Furthermore, performance in the 0 degree position was the poorest for the five angles used. It seems worthwhile to note that the 0 degree angle used in this study represents a horizontal keyboard, the keyboard used on typewriters and many other office machines.

The task and the equipment used in this study were selected so that the implications of the results would be applicable, to some degree, to a typing situation. At the same time it was recognized that a direct generalization of these results to typing and other situations would be improper.

Therefore, while the results of this study strongly suggest that certain innovations in keyboard design would result in greater efficiency, such a conclusion should await further studies.

In conclusion, multiple-finger tapping performance does vary as a function of the keyboard angle when performance is measured in terms of speed and errors.

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APPENDIX

QUESTIONS

Did you try to tap faster in one position compared to the others? Which one?

Do you think that you did tap faster in any position? Which one?

To tap fast in all positions, did you work harder in any particular position? Which one?

Did your arms get more tired in one position than in others? Which one?

If you could have a keyboard designed for your use, which angle would you choose?

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AN ABSTRACT

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This experiment was designed to study multiple-finger tapping performance as a function of the keyboard angle. It was designed to determine the optimal keyboard angle in terms of tapping speed, number of errors, and fatigue. Tapping speed was considered the most important measure of performance.

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Both the performance of the subjects and their verbal statements indicated that the optimal keyboard angle would be either the 44 or the 66 degree position. Furthermore, performance in the 0 degree position was the poorest for the five angles used. It seems worthwhile to note that the 0 degree angle used in this study represents a horizontal keyboard, the keyboard used for typewriters and many other office machines.

The task and the equipment used in this study were selected so that the implications of the results would be applicable, to some degree, to a typing situation. At the same time it was recognized that a direct generalization of these results to typing and other situations would be improper. Therefore, while the results of this study strongly suggest that certain innovations in keyboard design would result in greater efficiency, such a conclusion should await further studies.

In conclusion, multiple-finger tapping performance does vary as a function of the keyboard angle when performance is measured in terms of speed and errors.