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PERFORMANCE ON A REPETITIVE KEY PRESSING TASK AS A FUNCTION OF THE SPATIAL POSITIONING OF THE STIMULUS AND RESPONSE COMPONENTS

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PERFORMANCE ON A REPETITIVE KEY PRESSING TASK AS A FUNCTION OF THE SPATIAL POSITIONING OF THE STIMULUS AND RESPONSE COMPONENTS

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FOREWORD

This report represents a study designed to investigate the efficiency in performing a key-pressing task as a function of the spatial position of the stimulus and the response components.

This report was prepared by the University of Wisconsin under Contract No. AF18(600)-54. The contract was initiated under a project identified by Research and Development Order No. 694-49, "Human Engineering Research in Fire Control and Missile Control Systems." The contract was administered by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center with Mr. John W. Senders acting as Project Engineer.

ABSTRACT

A stimulus panel and a response keyboard occupied, independently, positions that were to the left, right or in front of the operator. Efficiency in key pressing was determined for each of the nine possible combinations of positions of stimulus display and response keyboard. A 9 x 9 Latin square design, with two replications, was used. Two modes of stimulus presentation were employed: (1) under self pacing, S kept his fingers on the response keyboard, matching the stimulus patterns which succeeded one another as fast as they were matched: (2) under automatic pacing, S returned to a rest position between matching successive patterns which were presented approximately six seconds apart. Response time and number of key presses (an error index) were measured in both automatic pacing and self pacing. In addition, latencies were measured in the automatic paced procedure.

The principal results of this experiment were as follows: (1) The optimal arrangement was obtained when both units were in front of the S. (2) Response times were 15% to 35% greater when the stimulus and response units were on opposite sides of the S (15% greater with the self paced procedure, 35% greater with the automatic paced procedure). These increases are small in contrast with increase in response time as great as 100% obtained in the previous experiments of this series where the effects of interferring with natural angular and linear stimulus-response correspondences were investigated.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

This paper is the third in a series (4, 5) dealing with some human engineering aspects of perceptual-motor behavior. It reports an experiment designed to find the relative efficiencies of a number of spatial positionings of a stimulus panel and a response keyboard used in a repetitive key-pressing task. The general problem of the location of the work space has been dealt with by the time and motion study engineers (e.g., 1) and location discrimination has been studied by Fitts (2), but none of this work is quite applicable to the problem of continuous or intermittent psycho-motor performances such as that reported in this paper.

In practical situations, the human operator will generally have to perform a number of tasks in response to stimuli of various types. The operator may thus be considered as a link between a number of stimulus components and the corresponding response components of the physical apparatus. The efficiency of any one task is then just the efficiency of the corresponding triad

stimulus component ⟶ operator ⟶ response component.

It will often happen in arranging the apparatus representing the stimulus and response components for the separate tasks that some of these will compete for preferred space. Because of this competition, equipment for some of the tasks will have to be assigned to less preferred space or will be forced to depart from optimal arrangements in some other way. A judicious choice of a good arrangement of the complete set of apparatus will involve, in particular, evaluation of the relative efficiency of less preferred placement of the stimulus and response components for the individual tasks of lower priority. The purpose of this series of experiments is to give preliminary information from which these evaluations can be made about certain types of tasks without an uneconomical process of trial-and-error.

Each experiment of this series has employed a key-pressing task in which each key in a row of eight response keys is associated with a stimulus light in a similar row of eight. The stimuli themselves consist of patterns of these lights. The two previous reports have investigated the effects of distorting a "natural" correspondence between the stimulus pattern and the pattern of response keys. One of these (4) considered transpositions of the key-light associations in which some or all of the keys were associated with lights other than the natural ones. In the second study (5) the row of stimulus lights was displaced angularly with respect to the (horizontal) row of response keys. Determinations were made of preferred apparatus arrangements and of the loss of efficiency involved in the choice of the less efficient arrangements.

In the present experiment, nine arrangements of the stimulus panel and response keyboard were used: the stimulus panel occupied variously the right, left, and front positions, relative to the operator, and the response keyboard occupied similar positions, independently. Two indices of operator efficiency were investigated as affected by the spatial positioning of these two components.

METHOD

Apparatus. The Multiple Serial Discrimeter (MSD) used in this experiment is the same as that employed in previous work (4, 5), except for the substitution of a new, light-touch, keyboard. The MSD has been adequately described in those reports. Consequently, only a brief summary of its characteristics will be given here.

The MSD consists of five basic units:

1. Stimulus display panel.
2. Response keyboard.
3. Stimulus programming unit.
4. Control unit.
5. Graphic operations recorder.

The stimulus display panel, shown in Fig. 1, consists of a row of red

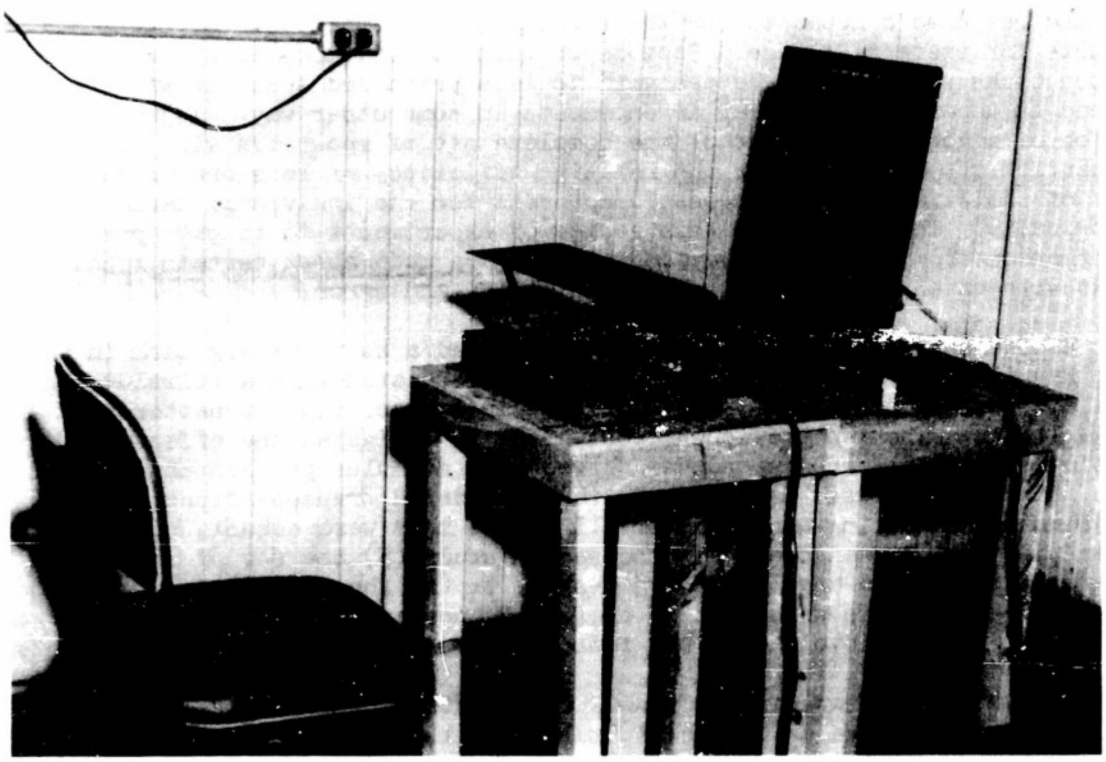

Fig. 1. Stimulus panel and response keyboard units of the Multiple Serial Discrimeter illustrating the FF treatment.

jeweled stimulus lights directly above a corresponding row of green jeweled response information lights. Each row consists of eight lights, grouped into two sets of four lights each. Illumination of some of the red lights constitutes a stimulus pattern. The green lights give response information to the S, as they light up when the corresponding key on the response keyboard is pressed down.

The response keyboard is also pictured in Fig. 1. The eight lucite keys, 3/4 in. wide, are mounted on a metal box, 13 in. by 8 in. The keys stand 3 1/2 in. above the table. The interval between the left and right hand sets of keys is 6 in. A slight force, between 1/2 oz. and 1 oz., applied at the end of a key, will close a microswitch. This activates the corresponding green response light and also produces a deflection of the associated recording pen on the Esterline Angus graphic operations recorder.

The stimulus programming unit is a pair of Western Union telegraph tape transmitters and associated relays which produce the successive stimulus patterns from the sequences of perforations on two paper tapes. Each stimulus light is associated with a unique position on the tapes. Whenever a hole in this position appears at the reading station, the corresponding stimulus light is lit.

The control unit governs the progression of the paper tapes and, hence, of the stimulus patterns. This progression may be of two types, self-paced or automatically paced. Under self pacing, the tapes are advanced one step yielding a new pattern of stimulus lights 0.01 sec. after the S has matched the preceding pattern. With automatic pacing, the new pattern comes on after a pre-set interval, whether the S has correctly matched the preceding pattern or not.

A 20-pen Esterline Angus graphic operations recorder was used to record the stimuli and responses. Each stimulus light and each response key is connected to a pen. Whenever any stimulus light is activated, or whenever any key is depressed, this fact is recorded by a deflection of the corresponding pen. The paper moves past the recording pens at a constant rate so that time, as well as error, measures may be obtained from these records.

The geometry of the stimulus-response positioning is illustrated in Fig. 2 where the rectangles indicate the three possible positions of the stimulus panel and the response keyboard. In each position, the stimulus display was about 28 in. from S's eyes, conforming to standards recommended by the Armed Forces-NRC Vision Committee as cited by Fitts (3, p. 1294).

The stimulus panel and the response keyboard were each mounted on small moveable tables 30 1/2 in. high. The right, left, and front positions of these tables defined a semi-enclosed space containing the chair, 20 in. high, on which the subject sat. A safety belt was used to strap S to the back of the chair in order to restrict his movements.

A fixation point, for use when S was not operating the keyboard, was placed 6 ft. high on a wall 6 ft. in front of S.

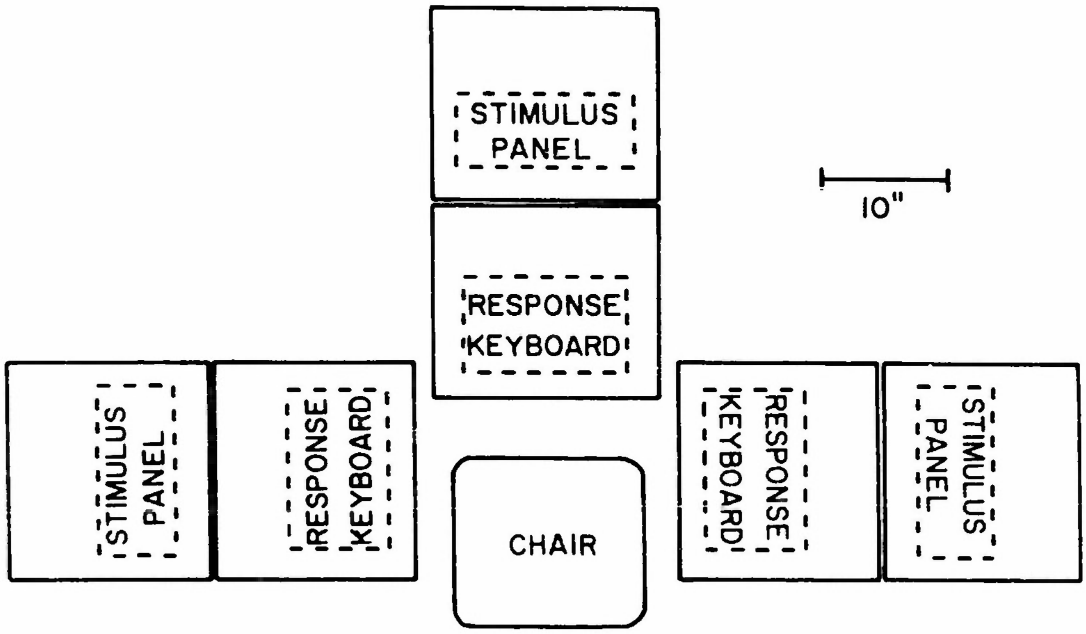

Fig. 2. Scale drawing illustrating position of operator's chair and the three positions of the moveable tables supporting the stimulus panel and the response keyboard.

Design and Procedure. The experimental design was a 9 x 9 Latin square with two replications. Rows corresponded to Ss, letters to treatments, and columns to the order of carrying out the treatments. The nine treatments were the nine possible positionings of the stimulus panel and the response keyboard. They were denoted by pairs of the letters L, R, and F, indicating the left, right, and front positions relative to the operator with the first letter of a pair standing for the position of the stimulus panel and the second letter of the pair giving the position of the response keyboard in that treatment.

Within each treatment, Ss matched two blocks of 25 patterns of three stimulus lights each. Of these two blocks, one was administered under self pacing, the other under automatic pacing. Thus each S matched 25 x 2 x 9 = 450 patterns in the total experiment proper. In addition, an initial warm-up block of 25 patterns was given under self pacing with both the stimulus panel and the response keyboard in the front position.

Excepting the warm-up block, the sequence of pattern blocks was either ASSAAS..., or SAASSA..., where A stands for automatic pacing and S stands for self pacing. When any subject received one of these sequences his replicate received the other.

The 450 three-light stimulus patterns used in the experiment proper were composed of consecutive series of 56 patterns, each series being randomly arranged, except that each possible three-light pattern occurred only once in each series. In addition, no pattern was the same as its successor.

Ss were run individually. Instructions were given with a tape recorder with S strapped in his chair. At the beginning of each block of patterns, S sat with his hands on his knees, looking at the fixation point. In response to a cue signalling the first pattern, he proceeded to match this pattern. Thereafter, the procedure diverged according to the type of pacing being employed. Under self pacing, S continued in action, matching the new patterns which came on as quickly as he matched the old ones. Under automatic pacing, S returned to his initial posture until the cue signalled the arrival of the next pattern.

S was permitted to use two cues in determining the arrival of new patterns, watching the stimulus panel from the corner of his eye, or listening for the distinct click emitted by the control unit in advancing patterns. Ss generally preferred to use the click. The interval between successive patterns in an automatically-paced group was about 6 sec. This interval was occasionally but unsystematically changed by as much as 2 sec during the course of all blocks run under automatic pacing in order to avoid conditioning S to the time interval.

A one-minute rest period was given between successive blocks of stimulus patterns. This allowed sufficient time to change the position of the stimulus panel and the response keyboard when a new treatment was to be used.

Subjects. Subjects were 18 male students at the University of Wisconsin who had volunteered to serve as paid subjects at the Laboratory of Experimental Psychology. In order to reduce practice effects, Ss were selected unsystematically from those who had already served in an earlier experiment, using the same apparatus in a nearly identical task. Two additional conditions were imposed: (a) all Ss were right-handed; and (b) all Ss had scored under 50 sec. on each of the last four trials of matching a self paced block of 25 three-light patterns in the earlier experiment. In all cases, there was a seven day interval between S's performance in the two experiments.

RESULTS

Only the last 15 stimulus patterns of each block of 25 were scored, the measurements being read from the Esterline Angus records. For both the self-paced and automatically-paced blocks, total number of key presses and total response time for the 15 patterns were taken. Number of errors was obtained by subtracting $3 \times 15 = 45$ from the number of key presses. In addition, the total latency (latency equals time from onset of stimulus to first key press) for the 15 patterns was measured for automatically-paced blocks. The 15 patterns were scored as a whole for the self-paced blocks. For automatically-paced blocks, the patterns were read individually, although the total scores for the 15 patterns were used in the analysis. Time scores were made to the nearest 0.1 sec.

Three statistical tests were employed. Analysis of variance of the 9 x 9 square forming the experimental design provided tests of learning, differences between Ss, between treatments, and between the two replications of the square. The scores for the nine treatments were used to form a 3 x 3 square with stimulus panel position and response keyboard position as orthogonal factors. This square was analyzed to test the influence of the two factors and of their interaction. Finally, a more exact specification of the relative efficiency of the treatments was made with the Tukey gap test (6)[1].

Angle between stimulus panel and response keyboard was taken as the most important single physical variable. The angle has the nominal values of 0°, 90°, and 180° although the angles are somewhat more acute if S is considered as the center of the system (see Fig. 2). In Fig. 3 the average times per pattern for all the data of the three recorded measures are plotted as a function of the angle between stimulus and response units. The numerical data are presented in Table 1.

Error data presented in Table 1 exhibited somewhat the same trend as the time measures but with less uniformity. Analysis of variance on the total number of errors yielded statistically significant differences only between Ss (.001). Consequently, these data were not analyzed further.

Automatically-Paced Procedure. (a) Response Time. The trend of these data, exhibited in Fig. 3, conforms to expectation. The response time increases with angle between stimulus panel and response keyboard. For a given angle, the results are quite orderly. The average times for the two 180° treatments, RL and LR, lie close together. The RF, LF, FR, and FL averages, each a 90° separation, lie within a 0.1 sec. interval. At 0°, the LL and RR averages lie together and somewhat higher than the FF treatment score.

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[1] Only the first step of this test was used. The 0.01 level was used instead of Tukey's 0.05 level of significance.

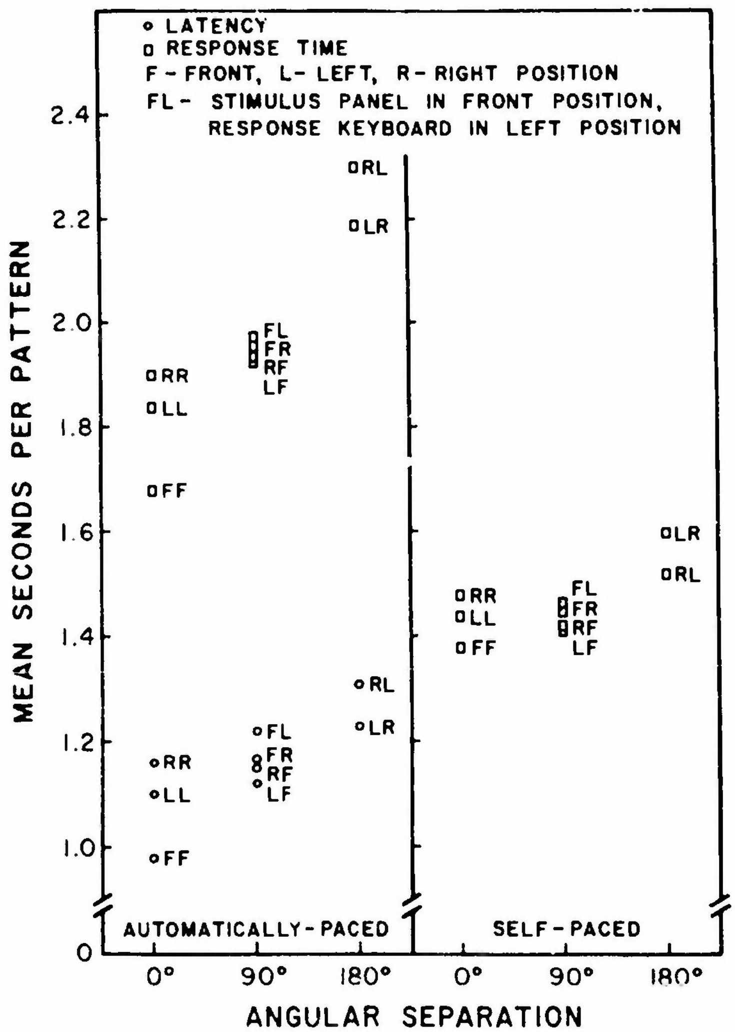

Fig. 3. Variation of mean time per stimulus pattern with angular separation of stimulus panel and response keyboard: response time and latency for automatic pacing; response time for self pacing.

These statements are supported by the statistics. Analysis of variance of the 9 x 9 square as summarized in Table 2 yielded significant differences (.001) between Ss, between treatments, and between ordinal position of treatments. Thus, it may be concluded that relative position of stimulus panel and response keyboard, individual differences, and learning all had a significant influence on the outcome.

TABLE I

Mean Scores for Response Times, Latencies and Errors.

		Location of Response Keyboard			
		Left	Front	Right	
	Left	1.84	1.93	2.19	Response Time
	Front	1.97	1.68	1.96	Automatic
	Right	2.30	1.94	1.90	Pacing
	Left	1.10	1.12	1.23	Latency
	Front	1.22	0.98	1.16	Automatic
Location	Right	1.31	1.15	1.16	Pacing
of	Left	1.44	1.41	1.60	Response Time
	Front	1.47	1.38	1.45	Self
Stimulus	Right	1.52	1.42	1.48	Paced
Panel	Left	1.81	2.03	2.57	Errors
	Front	1.79	1.91	1.93	Automatic
	Right	2.31	1.83	1.93	Pacing
	Left	1.17	1.04	1.36	Errors
	Front	1.19	1.08	1.26	Self
	Right	1.50	1.20	1.47	Paced

Analysis of variance on the 3 x 3 square, summarized in Table 3, with stimulus panel position and response keyboard position as orthogonal factors showed that both factors and the interaction were significant (.001).

Using the Tukey gap test, to distinguish treatments that led to statistically significant differences in performance, gave the following separation:

$$FF < LL < RR < (LF, RF) < (FR, FL) < LR < RL$$

Here, as below, a $<$ sign indicates that the treatment on its left took significantly less time than the treatment on its right. Parentheses enclose treatments not statistically separable from one another.

(b) Latency. These data are plotted in Fig. 3 and listed in Table 1. The same general trend appears in the latencies as in the response times, although the magnitude of the differences between the various treatments is somewhat smaller.

Analysis of the 9 x 9 Latin square, Table 2, showed significant differences between treatments (.01), and between Ss (.001). Learning did not

TABLE II

Analysis of Variance of the 9 x 9 Latin Square.

Source of Variance	df	Sum of Squares	F
(a) Response Time: Automatically Paced Procedure			
Subjects	8	2,320.11	22.21***
Order of Treatments	8	505.43	4.84***
Treatments	8	1,073.20	10.27***
Between Squares	1	38.52	
Error	136	1,775.83	
(b) Latency: Automatically Paced Procedure			
Subjects	8	1,858.49	20.54***
Order of Treatments	8	59.15	
Treatments	8	271.60	3.00**
Between Squares	1	27.21	
Error	136	1,538.30	
(c) Response Time: Self Paced Procedure			
Subjects	8	1,120.99	17.15***
Order of Treatments	8	139.89	2.14*
Treatments	8	140.89	2.16*
Between Squares	1	42.93	5.25**
Error	136	1,111.26	
(d) Key Presses: Automatically Paced Procedure			
Subjects	8	17,567.68	8.52***
Order of Treatments	8	2,621.46	
Treatments	8	2,209.68	
Between Squares	1	512.00	
Error	136	35,050.86	
(e) Key Presses: Self Paced Procedure			
Subjects	8	10,815.08	9.35***
Order of Treatments	8	696.64	
Treatments	8	824.08	
Between Squares	1	43.55	
Error	136	19,657.51	

*Significant at .05 level of confidence.
**Significant at .01 level of confidence.
***Significant at .001 level of confidence.

TABLE III

Analysis of Variance of the 3 x 3 Square with Stimulus Panel Position and Response Keyboard Position as Orthogonal Factors.

Source of Variance	df	Sum of Squares	F
(a) Response Time: Automatically Paced Procedure			
Between Stimulus Panel Positions	2	196.58	7.53***
Between Response Keyboard Positions	2	252.11	9.65***
Stimulus Panel Position x Response Keyboard Position	4	624.51	11.95***
Error	136	1,775.83	
(b) Latency: Automatically-Paced Procedure			
Between Stimulus Panel Positions	2	46.18	
Between Response Keyboard Positions	2	107.38	4.75*
Stimulus Panel Position x Response Keyboard Position	4	118.04	
Error	136	1,538.30	
(c) Response Time: Self-Paced Procedure			
Between Stimulus Panel Positions	2	16.72	
Between Response Keyorad Positions	2	71.69	4.39*
Stimulus Panel Position x Response Keyboard Position	4	52.48	
Error	136	1,111.26	

*Significant at .05 level of confidence.
***Significant at .001 level of confidence.

have a significant effect, in contrast to the results for the response times. Analysis of the 3 x 3 orthogonal square, Table 3, yielded significance only between response keyboard positions (.05). With the Tukey gap test, the following separation of treatments was obtained:

$$\mathrm{FF} < \mathrm{LL} < \mathrm{LF} < (\mathrm{RF},\ \mathrm{RR},\ \mathrm{FR}) < (\mathrm{FL},\ \mathrm{LR}) < \mathrm{RL}.$$

Self-Paced Procedure. The per pattern averages of response time for the self paced procedure, Fig. 3, show about the same features as response times for the automatically paced results. The range of variation is, however, considerably smaller.

Analysis of the 9 x 9 square, Table 2, resulted in significant differences between subjects (.001) and between treatments, between ordinal position of treatments and between squares (.05). Analysis of the 3 x 3 square, Table. 3, allows only the conclusion that the position of the response keyboard had a significant influence (.05). Neither stimulus panel position nor the interaction had significant effects. The Tukey gap test resulted in the following separation of treatments:

$$\mathrm{FF} < (\mathrm{LF},\ \mathrm{RF}) < (\mathrm{LL},\ \mathrm{FR}) < (\mathrm{FL},\ \mathrm{RR}) < \mathrm{RL} < \mathrm{LR}.$$

Here some of the zero degree treatments are not superior to the 90° treatments, in contrast to the corresponding scores obtained with the automatically paced procedure.

DISCUSSION

Scores from the automatically paced procedure were more affected by position of stimulus and response units than were the self paced scores. Matching times ranged from about 1.4 to 1.6 sec. per pattern for the most and least favorable treatments under self pacing. The corresponding figures for automatic pacing were 1.7 and 2.3 sec. Thus, the percentage losses were about 15% for self pacing and about 35% for automatic pacing. This result, as well as the fact that even the least favorable self paced treatments, LR and RL, were about as good as the most favorable automatically paced treatment, FF, was not unexpected in view of the different operating conditions. In automatic pacing, the S had to respond first to the cue, and then to the stimulus proper. In doing so he had to execute certain gross bodily movements. With self pacing, these postural movements were not required, and cue and stimulus were identical. This conclusion is the more significant in that the automatic pacing procedure presumably approximates more closely the operating conditions in many practical situations.

It is possible to obtain more information on the performance degradation than is given by its dependence on angle between stimulus panel and response keyboard. Average matching times as a function of stimulus panel position only, and as a function of response keyboard position only are shown in Fig. 4.

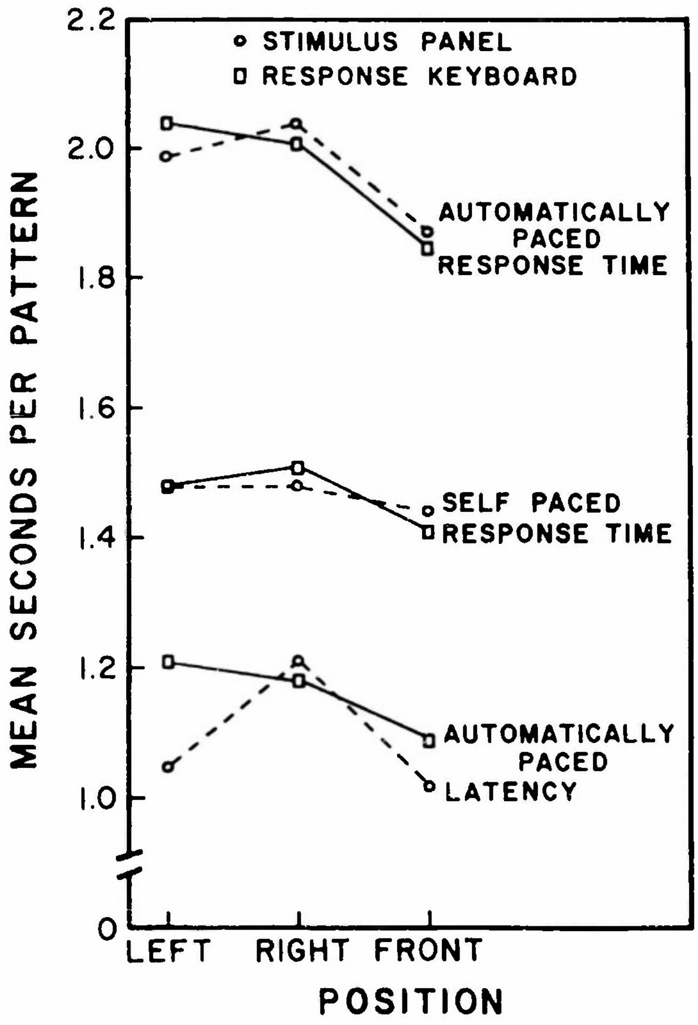

Fig. 4. Mean time per stimulus pattern for each stimulus panel position averaged over the response keyboard positions, and for each response keyboard position averaged over the stimulus panel positions: response time and latency for automatic pacing; response time for self pacing.

The analysis of the 3 x 3 square shows that the position of the response keyboard was a significant factor in all three of the time measures taken. In addition, for the automatically paced response times, the position of the stimulus panel and its interaction with keyboard position also produced significant effects. The interaction implies that the position of the response keyboard had a differential effect on the various positions of the stimulus panel.

Except in one case, the treatments at a given angular separation preserved the same order in time for all three time measures. The Tukey gap test gave considerable separation of treatments for all three sets of scores. For some treatments, however, the separation was based on rather small time differences so that, in those cases, it is doubtful whether the present results should be generalized to other situations.

Latencies ranged from about 1.0 to 1.3 sec. for the most and least favorable treatments, respectively. By subtracting the latencies from the response times, the time actually spent at the keyboard matching the stimulus pattern is obtained. These times range from about 0.7 to 1.0 sec , a loss of 0.3 sec in going from most to least favorable treatment. Thus, under automatic pacing, one-half of the loss in performance arose in perceiving the stimulus in an awkward position and moving to attack the keyboard in an awkward position. The other half of the loss arose in the manipulatory process at the keyboard itself. It should be noted that this was not accompanied by a significant change in the number of errors.

The above results indicate that a less preferred spatial positioning of stimulus panel and response keyboard produces a much smaller degradation in reaction time and response accuracy than results from interference with the natural correspondence between the stimulus and response components investigated in the previous experiments of this series. Increases of response time from 15% to 35% were found in this experiment. Transpositions of the natural response key - stimulus light associations (4) and angular non-correspondence between stimulus panel and response keyboard (5), however, gave increases as great as 1500%. It would seem, therefore, that stimulus and response components might better be displaced *in toto* rather than be subjected to angular or transpositional non-correspondence of stimulus and response elements (4, 5).

SUMMARY AND CONCLUSIONS

The results of an experiment investigating efficiency in a key pressing task as a function of spatial positioning of the stimulus panel and response keyboard are reported. The stimulus panel and the response keyboard occupied positions that were to the left, right, or in front of the operator. The nine possible combinations of positions of stimulus display and response keyboard were used as treatments in a 9 x 9 Latin square with two replications. Two modes of stimulus presentation were employed within each treatment: (1) under self pacing, S kept his fingers on the response keyboard, matching the stimulus patterns which succeeded one another as fast as they were matched; (2) under automatic pacing, S returned to a rest position between matching successive patterns which were presented approximately six seconds apart.

Five sets of scores were taken. Response time and number of key presses (an error index) were measured in both automatic pacing and self pacing. In addition, latencies were measured in the automatic paced procedure.

The following results were obtained:

1. With the self paced procedure, response times were 15% greater when the stimulus and response units were on opposite sides of the S than for the optimal arrangement where both units were in front of S. The corresponding increase for automatic pacing was 35%.

2. For automatic pacing, half of the decrease in efficiency arose in the manipulatory process at the keyboard. The other half was associated with the additional movements necessary in the less efficient treatments.

3. No significant differences in errors were observed among the various treatments.

4. Position of the response keyboard exerted a significant effect on all three time measures, the front position being preferred, and the left position giving poorest results. For automatic pacing, the position of the stimulus panel and its interaction with the response keyboard were also significant factors, the front position being best and the right position poorest.

5. For each time measure, the different treatments showed considerable separation when tested with the Tukey gap test.

The present results are contrasted with increases in response time as great as 1500% obtained in the previous experiments of this series where the effects of interfering with natural angular and linear stimulus-response correspondences were investigated.

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