ON RESPONSE-RESPONSE COMPATIBILITY

by

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One of the factors that has been found to have a major effect on the efficiency of a man-machine system has been termed "compatibility". This concept refers to the phenomenon that the efficiency of a man-machine system cannot always be accounted for on the basis of the efficiency of the individual elements. Rather, consideration must be given to the interaction among the elements. A facilitative interaction of this type between a display and a control has been termed by Fitts (1952) as "stimulus-response compatibility" (hereafter referred to as "S-R Compatibility").

Whereas the present study is only indirectly concerned with S-R compatibility, it is felt that a short discussion of the findings and theory resulting from these studies is necessary in conveying to the reader the purposes of the present study.

Stimulus-Response Compatibility

The conditions under which S-R compatibility has been studied generally have the following characteristics: (a) a visual display by means of which a stimulus can be presented to the subject and (b) a control mechanism which is manipulated by the subject in response to the stimulus. It has been found (Fitts & Simon, 1952; Fitts & Seeger, 1953; Fitts & Deininger, 1954; Garvey & Knowles, 1953, 1954) that the efficiency of this type of ensemble is not a function of the particular display, or control, or operator taken alone; but rather, a function of the interrelations among the three.

A study by Fitts and Seeger (1953) should serve to exemplify the types of procedures used and results found in a representative S-R compatibility study. The task required of the subjects in this study was to make an eight-choice reaction. The responses were movements of a stylus from a central point in one of several directions.

Three different sets of spatial stimuli and three different response mechanisms were paired in all possible stimulus-response (S-R) combinations to make up the nine experimental conditions used. In Stimulus Set A, eight lights were arranged in the form of an octagon and the onset of any one of these constituted a stimulus. In Stimulus Set B, four lights arranged in the form of a cross were used; they were presented singly and also as adjacent pairs, thus providing eight stimuli. In Stimulus Set C, a pair of left-hand horizontal lights and a pair of right-hand vertical lights were used; they were presented singly, and in all the possible combinations that could be formed by using one light from each pair.

Response Conditions A, B, and C were in spatial correspondence with Stimulus Conditions A, B, and C, respectively (see Fig. 1). Under response Condition A and Response Condition B only one stylus, held in the right hand, was used. Under Response Condition C, two styli were used, one held in each hand and either one or both had to be moved in making each response.

Three different measures were used; the mean time to initiate a response in seconds, the percentage of erroneous responses, and the amount of information lost are indicated. The maximum information that could be transmitted was 3 bits per response. The difference between the information actually transmitted and the maximum possible information was the amount of information lost.[1]

It will be noted in Fig. 1 that each stimulus set has a different optimum response set and, conversely, each response set has a different optimum stimulus set. Such a finding is a demonstration of an S-R compatibility effect. The results are interpreted to mean that one cannot talk about a

1. For a definition of "information" and "bits" the reader should refer to Miller (1953).

FIGURE I

Mean Scores For Eight S's In Each Of The Experimental Groups

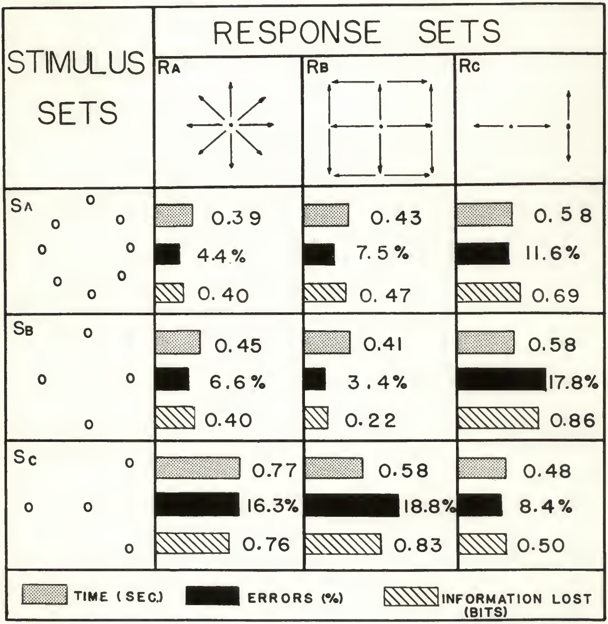

Figure 1 reprinted from Fitts, P.M., & Seeger, C.M. S-R Compatibility: Spatial Characteristics of stimulus and response codes. J. exp. Psychol., 1953, 46, p 203.

"best type of display code" or a "best type of response code"; but rather, one must say one S-R ensemble is better or worse than other ensembles.

Fitts and his colleagues (Fitts & Simon, 1952; Fitts & Seeger, 1953; Fitts & Deininger, 1954; Fitts, Bahrick, Noble, & Briggs, 1959) have interpreted compatibility in terms of modern communication theory, conceiving of man as a complex information processing or communication system. This interpretation makes use of the idea of a hypothetical process of information transformation or recoding in the course of perceptual-motor activity and assumes that compatibility is at a maximum when recoding processes are at a minimum. It has been of major concern to the investigators in this area to determine what variables are important in determining the ease or difficulty of these transformation processes. Fitts et al. (1959) have presented the following hypotheses which were constructed to specify a number of variables which affect the efficiency of these transformation processes.

(a) Population Stereotypes

> The degree of population stereotype in an S-R ensemble is positively correlated with level of performance.

(b) Anticipatory Sets

> Performance will be facilitated to the degree that individuals can anticipate the possible events to be encountered and their probabilities.

(c) Concepts

> Whenever the information-transformation rules and the probabilities appropriate to a particular task can be specified by commonly understood concepts then subsequent performance will be high.

(d) S-R Congruence

> Performance will be increased with an increase in the spatial correspondence between S and R and in the familiarity of the spatial relations.

(e) Ambiguities

When ambiguities regarding figure-ground relations, command versus error data, intervening machine transformation, and coordinate systems occur, then a low degree of compatibility will result.

Response-Response Compatibility

Reference has also been made to a "response-response compatibility" effect (hereafter referred to as R-R compatibility) (Fitts & Seeger, 1953; Fitts, et al., 1959). A review of the literature resulted in finding only two short sentences concerned with R-R compatibility. Fitts & Seeger (1953, p. 199) state, "The concept of compatibility can be extended to cover relations between concurrent stimulus activities, such as take place during simultaneous listening and looking, as well as relations between concurrent motor responses". (italics are writer's) At a later date Fitts et al. (1959, p. 9.4) are only slightly more specific in stating; "Response-response (R-R) compatibility effects arise whenever two or more separate response processes are carried on concurrently ... " While seemingly tenable hypotheses, the writer finds no experimental evidence to clarify or to give support to these statements.

How may these two statements be interpreted when thinking in terms of the theoretical framework formulated for S-R compatibility? It is clear that the concept of compatibility has been formulated in the general context of encoding and information transformations (Fitts & Seeger, 1953; Fitts & Deininger, 1954; Fitts et al., 1959). It is not clear, however, whether Fitts and his colleagues would describe R-R compatibility by reference to the relations between the "response codes" or to the relations between each "response code" (considered separately) and the "stimulus code".[1]

1. "Stimulus codes" and "response codes" are also conceptualizations of Fitts and his colleagues (Fitts et al., 1959, Ch. 9).

If the relations between each response code and the stimulus code were considered to be the only important factor, it would be needless to consider R-R compatibility, for the efficiency of the system could be predicted in terms of the theory set forth for S-R compatibility. On the other hand, it does not seem meaningful to talk about the relations between two response codes without considering the stimulus code for, by definition, an encoding process must have both a stimulus code and a response code. "An information transformation or encoding process is achieved by applying a set of rules whereby the symbols of one code, the stimulus code, are mapped into corresponding symbols of another code, the response code " (Fitts et al., 1959, p. 9.2).

In view of these arguments, the writer believes that it would be most meaningful to consider both the relations between the "stimulus code" and each "response code", and the relations between the two "response codes". These would appear to be interactive processes, each being partly dependent upon the other. A descriptive symbolization for this process might be as follows.

The double tipped arrows imply that there is an interaction between each element and every other element in the triad. According to this symbolization, there is no such thing as R-R compatibility, but rather, stimulus-response-response compatibility. Hereafter the writer will refer to this conceptualization as S-R-R compatibility.

Other Relevant Literature

There have been a host of studies designed to investigate cranking behavior on both single and dual control mechanisms. Studies have been conducted to investigate (a) the effects of crank radius and drag on free or continuous cranking performance (Reed, 1949), (b) the plane of operation of controls (Norris & Spragg, 1953), and (c) the direction of movement of controls in relation to the direction of movement of the indicator or cursor (Carter & Murray, 1947) (Mitchell & Vince, 1951) (Norris & Spragg, 1953).

While these certainly seem to be important variables in the encoding process, they have little bearing on the problem at hand. These studies in investigating the effects of plane of rotation, "cursor-control relationships"[1], etc., have failed to hold constant the relationship between the two controls; thus, any possible response-response (R-R) effects were completely confounded with the other variables.

Time and motion literature specifies certain principals in regard to two-hand performance that are related to the present problem. Barnes (1958) has set forth the following principals:

1. The two hands should begin as well as complete their motions at the same time.

2. Motions of the arms should be made in opposite and symmetrical directions and should be made simultaneously.

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1. There appears to be some ambiguity in the literature in the use of the term "display-control relationships". In compatibility studies the term has been used in reference to the similarity in form (both geometrical form and coding form) between the stimulus panel and the control panel. In contrast to this, studies that have been concerned with tracking performance have used the term to depict the relationship between the direction of control movement and cursor movement. While it appears that both types of relationship are important in affecting perceptual-motor performance, and that both can be thought of in compatibility terms, it is nevertheless important that the reader be aware of the fact that they are two distinctly different phenomena and that they most likely affect behavior in distinctly different ways.

The writer prefers to limit the use of this term to the former sense. "Cursor-control relationship" will be used in referring to the latter relationship.

One cannot make the intuitive assumption, however, that the principles derived from the study of highly repetitious tasks would apply equally well to a situation in which the individual must respond to a discrete signal, encode the signal, and respond with a discrete - unreplicated response. Nor can one make the assumption that individuals naturally respond in the manner specified by these principals. It will be interesting to find how well these time and motion principals comply with the present results.

Statement of Problem

The problems to be studied are as follows. Given an S-R-R ensemble:

1. When the R-R relationships are held constant, does varying the S-R relationship have any effect on the efficiency of an ensemble?
2. When the S-R relationships are held constant, does varying the R-R relationship have any effect on the efficiency of the ensemble?
3. Are there interaction effects between the stimulus and control conditions?

Method

Subjects

The subjects for this study consisted of five right-handed and one left-handed males ranging in age from 18 to 35 years. These subjects had no defects in arm and shoulder dexterity nor in visual acuity. The subjects were volunteers from the spring semester General Psychology classes at Kansas State University.

Apparatus

The apparatus for this study was constructed so as to require a two-hand adjustment task of the subject. The subjects could, by manipulating two control cranks, adjust a mechanical stylus to any one of one hundred points on a ten-by-ten matrix.

The left-hand crank moved the stylus toward and (or) away from the S, whereas, the right-hand crank moved the stylus right and (or) left. The cranks could be manipulated either individually or simultaneously.

The major components of the apparatus were as follows: (1) a Subject's Control Panel, (2) a stimulus projector and screen, (3) an Experimenter's Control Panel, (4) instrumentation to measure direction and latency of initial movements, (5) an observation window, and (6) electrical connections. Each of these components will be described in turn. A schematic drawing of the top and side view of the apparatus may be seen in figures 2 and 3 respectively.

Subject's Control Panel. -- The Subject's Control Panel consisted of a display board, a chain and sprocket device for the mechanical manipulation of a mechanical stylus, and a right-hand and left-hand control crank (see Fig. 2).

The display board was constructed from a ½-inch thick sheet of hard finish masonite. The finished dimensions were 18 inches by 18 inches. One hundred metal plugs, each of which were 3/8 inch in diameter, were inserted in the board at 1-3/8 inch intervals, forming a ten-by-ten matrix of plugs. These plugs functioned as electrical contacts. The plugs were inserted so as to be flush with the upper surface of the board. They extended, however, ¼ inch below the underside of the board so as to facilitate electrical connection. The columns were lettered A through J along the upper edge of the board and the rows were numbered 1 through 10 along the left edge of the board. The board was mounted on a 4 inch high frame which, in turn, was mounted on a flat table top. The board was situated 35 inches above the floor level.

A mechanically operated stylus, which slides along the surface of the display board, was driven by a chain and sprocket device as pictured in Figure 2. The stylus was constructed from a triangular shaped piece of plexiglass. A small metal rod (3/16 inch in diameter) was inserted vertically through the apex of the plexiglass triangle. When Chain C, to which the stylus was attached, was moved - the small rod was caused to slide across the surface of the board. An electric current was carried to this rod via an electric wire extending from the ceiling of the experimental room.

One-half inch diameter steel rods were mounted at both the upper (Rod A) and the lower (Rod B) edges of the control board. A $3\frac{1}{2}$ inch diameter sprocket was attached securely to each end of both rods (Sprockets A & A' and B & B'). A $\frac{1}{2}$ inch wide bicycle type chain connected Sprockets A and B on the left side and Sprockets A' and B' on the right side. The steel rods acted as drive shafts to turn all sprockets simultaneously.

One-half inch diameter steel rods were also mounted along the left (Rod C) and right (Rod C') edges of the display board. A keyway $\frac{1}{4}$ inch wide, 1/8 inch deep, and 18 inches long was cut in the right-hand rod (Rod C'). A sprocket (Sprocket C') with 1/8 inch studs inserted through the hub was constructed to fit Rod C'. The studs acted as keys which fit loosely into the keyway. This arrangement permitted the Sprocket to slide along the entire length of the keyway and at the same time be rotated by turning Rod C'. A bicycle type chain (Chain C in Figures 2 & 3) connects Sprockets C and C'.

A finger brace was attached to both chains A and B (see Fig. 2)and encircled the sprocket hub. Thus, as the vertical chains were moved toward and away from the subject (hereafter "subject" will be abbreviated as S),

FIGURE 2

SUBJECT'S CONTROL PANEL

TOP VIEW

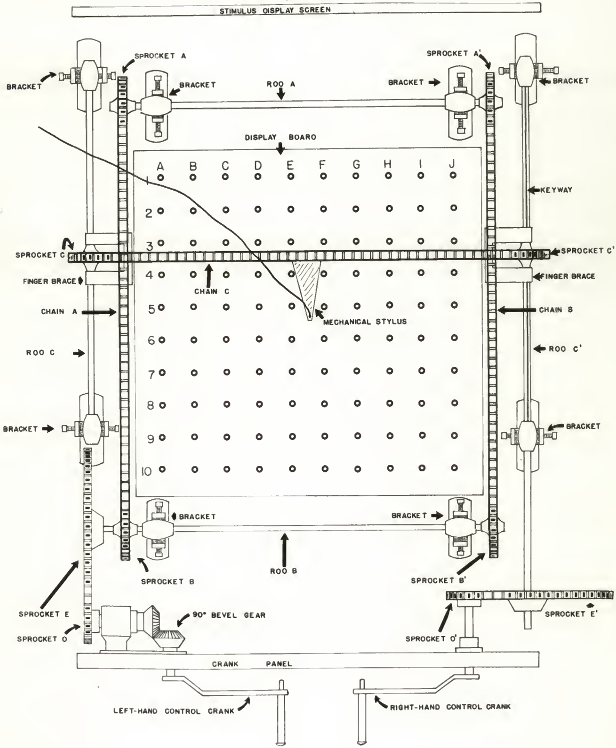
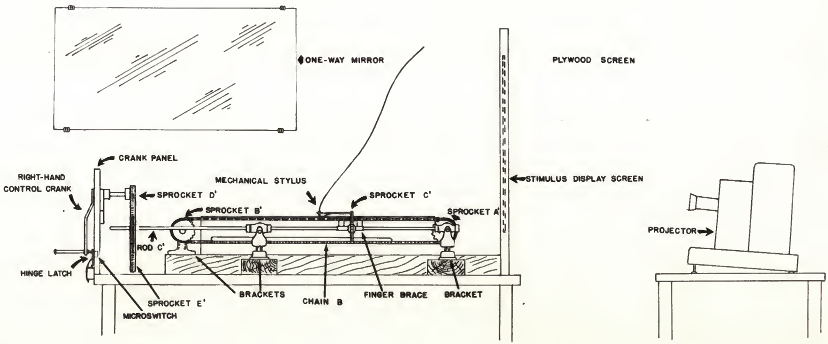


FIGURE 3

SUBJECT'S CONTROL PANEL

RIGHT LATERAL VIEW



Sprockets C and C' were forced, by the finger braces, to move in unison. This arrangement permitted the stylus to be moved in both the vertical and the horizontal planes simultaneously.

The right-hand and left-hand control cranks, each having a radius of 6-¼ inches, were mounted on a vertical wooden panel situated parallel to S's frontal body plane. The left-hand crank was connected so as to drive Rod C' and thus produce horizontal movement of the mechanical stylus. The left-hand crank was connected so as to drive Rod B and thus produce vertical movement of the mechanical stylus.

These connections between the rods and the cranks were made by means of a second chain and sprocket system. A nine-tooth sprocket was mounted on a rod extending through the wooden panel from the right-hand crank. The same type sprocket was mounted on a 90 degree bevel gear which was connected to the left-hand crank. (Sprockets D and D' in Fig. 2) A 70-tooth sprocket was mounted on Rods B and C' respectively. (Sprockets E and E') The 9 and 70-tooth sprockets of each side were connected with a bicycle type chain. This arrangement permitted a 7.8 : 1 reduction in gear ratio to be generated. Thus, to move the stylus three spaces on the control board (which was the shortest required movement) required 5 complete revolutions of the crank.

Projector and Screen. -- A Model "B" Duning Animatic projector was used to project the stimuli onto the rear side of a square, translucent screen. The screen was located directly in front of S at a distance of 45 inches. The stimuli were projected on the screen at a point roughly 14 degrees below eye level.

The signals were photographed on alternate frames of a 16 mm film strip. The shutter mechanism of the projector was operated by means of a Pendant switch located on the experimenter's control panel (hereafter "experimenter" will be abbreviated as E). A frame change required 1/200 second for completion.

Experimenter's Control Panel. -- The Experimenter's Control Panel consisted of a "Switch Board", three Standard Electric Time Clocks, a "Master Activation Switch", and a pendant switch for the activation of the shutter mechanism on the projector.

The "Switch Board", an 18-inch by 18-inch sheet of $\frac{1}{2}$-inch plywood, contained one hundred banana jacks inserted in the form of a ten-by-ten matrix. The columns were lettered A through J and the rows numbered 1 through 10. Each jack on the "Switch Board" had a corresponding plug on the Subject's Control Board. Each banana jack was wired directly to its corresponding plug. With this arrangement E could, by inserting a banana plug in a jack, activate any desired plug on the Subject's Control Board.

Two of the three Standard Electric Time Clocks were used to measure the latency of the initial movement of the control cranks. (A more thorough discussion of this mechanism is presented in the following section.) The third clock measured the total time consumed in making a given adjustment.

The Master Switch, A DPST, normally-open toggle switch, was wired to the three Standard Electric Time Clocks. Closing this switch activated all three clocks simultaneously.

The pendant switch was connected to the projector by means of a long electrical cord. This switch permitted E to activate the shutter mechanism on the projector (change a frame) without moving from the observation window.

Mechanism For Measuring Initial Crank Movement. -- The mechanism discussed in this section is, geographically, a part of the Subject's Control Panel but is functionally connected with the Experimenter's Control Panel. It is hoped that confusion will be avoided by discussing this mechanism in a separate section.

This mechanism was designed to give two different measures of initial crank movement, viz., latency of initial movement and direction of initial movement. To measure latency, a normally-closed roller leaf type microswitch was fitted into an opening cut in the wooden crank panel. These switches were situated directly adjacent to the handles of the cranks when the cranks were in a six o'clock position. A hinge-latch was also mounted to the wooden panel directly below the microswitch (see Figs. 4 & 5). When this latch was placed in a twelve o'clock position, and the crank was placed in a six o'clock position, the handle depressed the latch which in turn depressed the microswitch. When the crank was moved $\frac{1}{2}$ inch in either the clockwise or the counterclockwise direction, the latch sprung down, releasing the microswitch.

To measure the direction of initial crank movement, a small lever with a V-shaped attachment on the upper end was mounted on the panel (see Figs. 4 & 5). When the cranks were placed in a six o'clock position and the levers were placed in a twelve o'clock position, the V-shaped attachment encircled a small bolt extending through the front side of the arm of the crank directly below the handle. When the crank was moved $\frac{1}{2}$ inch in either direction the lever was caused to fall 90 degrees in the appropriate direction.

Observation Window. -- A 4-foot by 8-foot plywood screen was erected along the left edge of the table upon which the apparatus was mounted. A 12-inch by 24-inch one-way mirror was mounted on the screen directly to the left of S. This arrangement shielded from view both E and the Experimenter's Control Panel but allowed E to observe S's performance through the one-way mirror (see Fig. 3).

Electrical Connections. -- It will be noted in Fig. 6 that there were two main electrical circuits, a 110 VAC circuit (Circuit A) and a 6 VDC circuit (Circuit B).

FIGURE 4

MECHANISM FOR MEASURING INITIAL CRANK MOVEMENT
(FRONT VIEW)

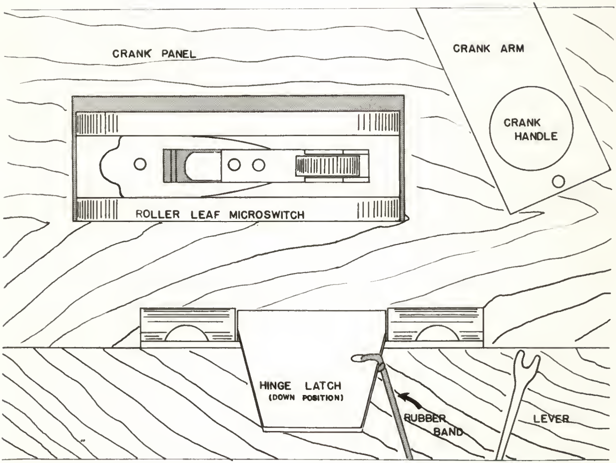
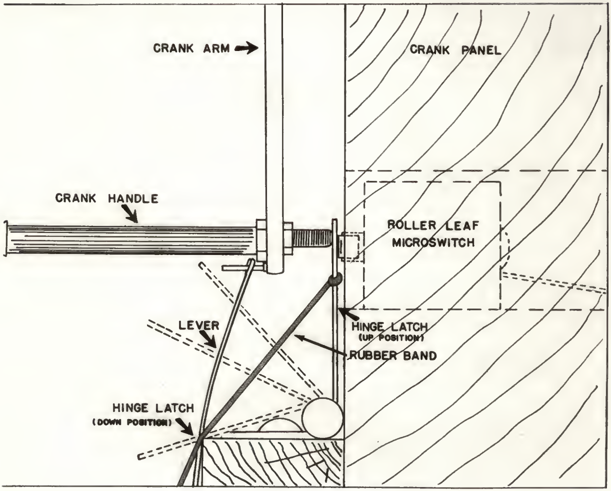


FIGURE 5
MECHANISM FOR MEASURING
INITIAL CRANK MOVEMENT
(RIGHT LATERAL VIEW)



Circuit A contains a normally open DPST wall type switch (S_1), two normally open roller type microswitches (S_2 & S_3) and three Standard Electric Time Clocks (C_1, C_2, & C_3).

The closing of the Master Activation Switch (S_1) simultaneously activates the three Standard Electric Time Clocks (C_1, C_2, & C_3). Time clocks C_1 and C_2 were controlled by microswitches S_2 and S_3, respectively. It will be recalled that these switches are depressed by the hinge latches. A $\frac{1}{2}$-inch movement of a crank released this latch which in turn, opened the circuit to the time clock to which it was attached. This arrangement provided a measure of the time elapsing between the closing of the Master Activation Switch and the first movement (of $\frac{1}{2}$-inch magnitude or more) of each crank.

Circuit B was powered by a Battery Eliminator with a 6 VDC output. The components of this circuit are: Experimenter's Control Board, the Subject's Control Board and a normally closed 6 VDC relay.

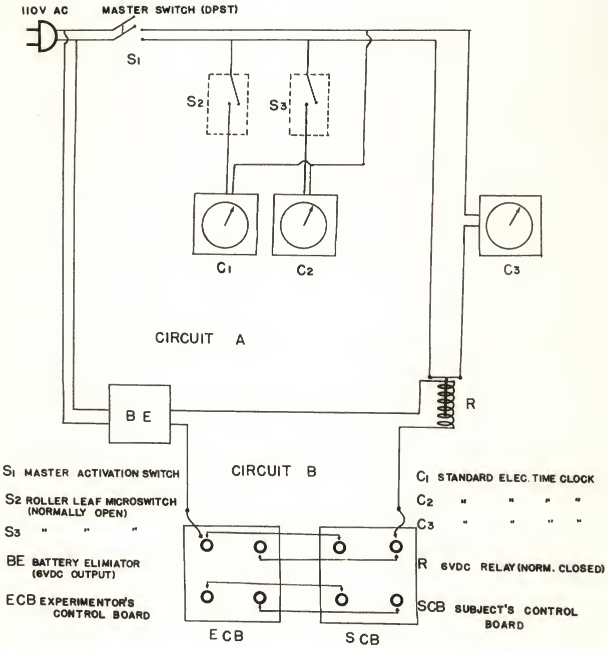
Each banana jack on the Experimenter's Control Board was connected with a corresponding plug on the Subject's Control Board. When the banana plug (which was connected to the battery eliminator) was inserted into a particular jack, it activated one of the plugs on the Subject's Control Board. This circuit remained open until the mechanical stylus (which was connected to the relay) came into contact with the appropriate plug. The occurrence of this contact operated the 6 VDC relay which opened Circuit A. The opening of Circuit A stopped the last time clock, C_3. This arrangement provided a measure of the time elapsing between the closing of the Master Activation Switch and the bringing of the Mechanical Stylus into contact with the appropriate plug on the matrix.

Stimulus Types

Three different types of stimuli were used. These were termed "Instruc-

FIGURE 6

WIRING DIAGRAM



tional Stimulus", "Digital Stimulus", and "Pictorial Stimulus". Figure 7 shows the form in which these three types were pictured on the screen.

The "Instructional Stimulus" gave the direction and distance of the next target in the series by displaying written instructions to move the stylus a given number of units in the horizontal and vertical planes. The digital stimulus gave the location of the next target by specifying its column (letters) and row (numerals). The "Pictorial Stimulus" consisted of a diagrammatic replication of the Subject's Control Board with the next target designated by having the appropriate plug covered by a large square.

Selection of Targets

Inspection will show that there are four possible combinations in regard to the relationships between movements of the two cranks. In Table 1, the symbol C refers to clockwise, and the symbol CC refers to counter-clockwise. Thus, for example, in Condition 1, the right-hand and the left-hand cranks are to be moved in counter-clockwise directions.

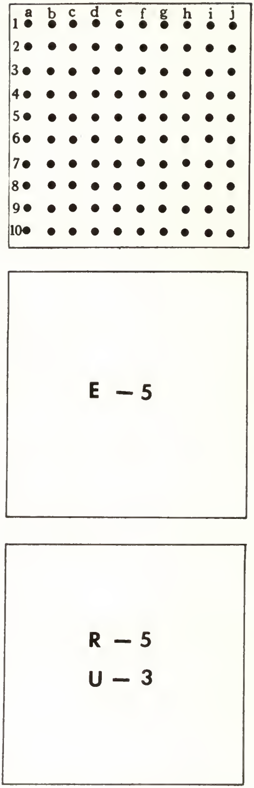
Table 1. Specification of response conditions

Condition	Right-Hand	Left-Hand
1	CC	CC
2	C	CC
3	C	C
4	CC	C

The statistical design of this study (discussed in a later section) demanded a series of targets which met each of the following requirements:

(1) Each of the four conditions shown in Table 1 should occur an equal number of times in the series.

FIGURE 7
STIMULUS TYPES



INSTRUCTIONAL

DIGITAL

PICTORIAL

(2) Each Condition should occur equally often at each stage of practice.

(3) The order of the Conditions should be randomized.

(4) The total travel space required by any series should be equal for all Conditions.

The series of targets selected to meet the previously stated demands are shown in Table 2. It will be noted that there are nine blocks of four targets each. Each block contains all four Conditions. The order of the conditions within each block were selected by printing the numbers one through four on four separate slips of paper. The slips were placed in a small box, mixed thoroughly, and drawn out one at a time. The order of the slips determined the order of the Conditions in the block. This procedure was repeated nine times, once for each block.

This arrangement met Requirements 1, 2, and 3, i.e., each condition occurs equally often (nine times) during the series, each condition occurs equally often at each stage of practice (once in each block), and lastly, the order of conditions are randomized within each block (avoiding predictability).

The fourth and sixth columns in Figure 8 give the travel distance required for the right-hand and left-hand, respectively. The numbers in these columns represent intervals or spaces between plugs. For example, in order to move the stylus from Plug 5-G to 10-D, the mechanical stylus must be moved three spaces by the right-hand crank and five spaces by the left-hand crank. Tabulation will show that the total travel distance is exactly the same for all conditions. This arrangement met the requirements prescribed in Requirement 4 above, i.e., total travel distance must be equal for all conditions.

The targets listed in the last (eighth) column of Table 2 function to position the stylus at a point from which the movements required in the next

Table 2. Target series

Block	Condition	Right-Hand Movement	Spaces Moved	Left-Hand Movement	Spaces Moved	Target	Adjustive Target
							5-G
	4	CC	3	C	5	10-D	
	1	CC	3	CC	5	5-A	
1	2	C	4	CC	4	1-E	
	3	C	5	C	3	4-J	
							8-B
	2	C	5	CC	3	5-G	
	3	C	3	C	5	10-J	
2	1	CC	4	CC	4	6-F	
	4	CC	4	C	4	10-B	
							5-F
	3	C	4	C	4	9-J	
	1	CC	5	CC	3	6-E	
3	2	C	3	CC	5	1-H	
	4	CC	5	C	3	4-C	
							2-A
	3	C	5	C	3	5-F	
	4	CC	3	C	5	10-C	
4	2	C	4	CC	4	6-G	
	1	CC	3	CC	5	1-D	
							1-G
	3	C	3	C	5	6-J	
	1	CC	4	CC	4	2-F	
5	4	CC	4	C	4	6-B	
	2	C	5	CC	3	3-G	
							3-H
	4	CC	5	C	3	6-C	
	3	C	4	C	4	10-G	
6	1	CC	5	CC	3	7-B	
	2	C	3	CC	5	2-E	
							7-A
	3	C	5	C	3	10-F	
	2	C	4	CC	4	6-J	
7	1	CC	3	CC	5	1-G	
	4	CC	3	C	5	6-D	
							5-I
	1	CC	4	CC	4	1-E	
	4	CC	4	C	4	5-A	
8	3	C	3	C	5	10-D	
	2	C	5	CC	3	7-I	
							6-E
	2	C	3	CC	5	1-H	
	4	CC	5	C	3	4-C	
9	3	C	4	C	4	8-G	
	1	CC	5	CC	3	5-B	

block may be made and yet remain within the limits of the Subject's Control Board. To clarify, suppose the stylus were resting on Plug J-9 of the matrix, and further suppose the next condition in the series to be Condition 3, which requires a movement to the right together with a downward movement. With the stylus resting on the extreme right edge of the board one could not select a target that would produce a further movement to the right without going beyond the limits of the board. A re-positioning movement was required only once per block. These movements were neither timed nor considered in the analysis of results.

The 36 Targets and the 9 Adjustive Targets were coded into the three stimulus types previously mentioned, i.e., Instructional, Digital, and Pictorial. Each stimulus in the series was photographed on single frames of a 16 mm film strip, leaving alternate frames blank. A separate film strip was made for each of the three different stimulus codes. The targets on all three film strips represent the same point on the Subject's Control Board; the only difference is in the coding of these signals.

Experimental Design

A preliminary study suggested that more than one experimental session would be required in order for performance on this task to become stabilized. To insure that this stability had been reached each S was required to proceed through three experimental sessions. This meant that each S had to make the adjustments for all of the three film strips once each day for three consecutive days. Approximately two hours were required for each session.

In order to control practice effects and order effects the following counter balanced design was used (see Table 3).

This systematic arrangement provided for counter-balancing of stimulus types for both subjects and sessions. This is to say, for a given S, each stimulus type occurs equally often at each stage of practice. Furthermore, all possible combinations of the three stimulus types occur in each series. This counter-balanced order permits analysis by S, by session, and (or) over all sessions and subjects.

Table 3. Order of presentation of the stimulus series.*

		Sessions 1	2	3
Subjects	1	DPI	PID	IDP
	2	PID	IDP	DPI
	3	IDP	DPI	PID
	4	DIP	PDI	IPD
	5	PDI	IPD	DIP
	6	IPD	DIP	PDI

* The symbol D refers to the Digital Series, I to the Instructional Series, and P to the Pictorial Series.

Procedure

Each S was accompanied into the experimental room, was instructed to stand in a position convenient for the manipulation of the cranks, and was read the following instructions:

> This is an experiment to determine how well individuals can manipulate a type of machine control. Your task will be to adjust this pointer (E points to stylus) to certain of these metal discs (E points to plugs) by manipulating the two cranks. You will notice that the left-hand crank moves the pointer in an up-down direction, that is, from one through ten. The right-hand crank moves the pointer in right-left direction, that is, from A through J. You may rotate the cranks a few times to get their feel. (The S at this point is allowed to manipulate the cranks to "get the feel" of them.)
>
> You will now note the two hinge latches situated on the lower left and lower right edges of the wooden panel. If the hinge latch is placed in an upward position and the cranks are placed in a six o'clock Position (E illustrates) you will find that the crank depresses the hinge latch which, in turn, depresses the microswitch.

You will also notice the two small metal levers directly under each hinge latch. When the hinge latches have been reset these levers may also be reset by simply placing them so the small fingers on the end of the lever encircle the small bolt extending from the arm of the crank. You will be responsible for re-setting both the hinge-latches and the levers after each trial.

Immediately after I say "ready", you will grasp the cranks and watch the screen in front of you. At a count of three after the ready signal is given you will see a picture flashed on the screen. This picture will tell you which one of the plugs is to be the target. You should then adjust the pointer to the target as rapidly and with as few errors as possible. The particular method of adjustment is entirely up to you. Remember, however, that both speed and accuracy are important since your score is determined by the time it takes to get each adjustment correctly performed along with a measure of the number of errors made in the adjustment. It is not necessary to have the pointer resting directly on the center of the disc. When you hear a click (E illustrated the click made by the relay) you will know you have made a correct adjustment and you should make no further movement. When you have had the pointer resting on the correct target for one second the picture will be immediately removed from the screen. When this happens, continue holding the pointer on the target until you are told to "reset". When I have given you this signal and you have completed the resetting operation, you will grasp the handles and await the ready signal signifying another trial. This same operation will be repeated throughout the experiment. Do you have any questions? (questions pertaining to the instructions were answered by re-reading the appropriate section of the instructions. Questions not pertaining to the instructions were deferred until after the experiment.)

You will notice that the pointer can be moved only so far in any direction. When you have the pointer beyond the outer row or column of discs you will notice a resistance in the crank. When this happens do not persist in that movement, for the ten-to-one gear ratio generates a good deal of power which makes it easy to damage the apparatus.

You will be presented with three different types of signals. These are called the instructional signal, the digital signal, and the pictorial signal. The instructional signal (E illustrates with an example printed on a poster card) tells you the number of spaces you are to move the stylus from where it is resting at the time you are presented the signal. You will note that R means right, L means left, U means up, and D means down. Thus if you were given a signal which read L-5, D-3 you would move the pointer to a point 5 spaces to your left and 3 spaces down. (E demonstrates)

> The digital signal (E shows S an example printed on a poster card) has a number-letter combination. You will notice that the number indicates a row and the letter indicates a column. (E demonstrates)
>
> The pictorial signal (E shows S an example printed on a postal card) is a diagrammatic replication of the matrix on which you adjust the pointer. A large square superimposed on one of the discs will indicate the position of the target.
>
> You will now be given three practice trials with each type of signal. Do you have any questions before we begin?

The S is given nine practice trials at this point. The targets for these practice trials were printed on separate poster cards but were otherwise the same as those pictured on the screen.

> Now we are going to start scoring. Until I tell you that a change will occur, the signal will be the __________, as on this card. (E illustrates) Now though, the signals will be displayed on the screen. Otherwise the task is just as it was before when we used the cards. Are there any questions?

On each trial in which measurements were taken the following operations were performed. These operations were repeated in this order, until the S had progressed through the entire series.

1. The S was instructed to "reset" (both the latches and the levers). Completion of this operation was followed by the "ready" signal given by E.

2. E threw the Master Switch and the pendant switch which simultaneously activated the three time clocks and presented the stimulus on the screen.

3. S began his adjustment. His initial crank movement stopped the corresponding time clock providing E with a measure of the latency of this movement. At the same time the corresponding lever was tripped and provided information as to the direction of the initial movement. The third time clock was stopped when S brought the stylus into contact with the correct plug.

4. E recorded the readings for the three time clocks and the direction of the initial movement for each crank.

5. E reset the Experimenter's Control Board by, (a) plugging the banana jack into the plug corresponding to the next stimulus in the series and, (b) resetting the three time clocks.

Upon completion of the first series S was asked to be seated until E had changed the film strip. After changing the film strip E read S the following instructions:

> We are ready to start scoring again so you may take your place. The next type signal will be the ________________. (E illustrates) Otherwise the procedure will be the same as before. Are you ready?

These instructions were again repeated before the start of the third series. Upon completing the third series arrangements were made for a second session on the following day. The S was then permitted to leave.

It was not found necessary to re-read the introductory instructions before the second and third sessions. The S's were told "the procedure will be the same as last time" and were asked if they had questions. Thereafter, S's were given the nine practice trials and then proceeded through the three series.

Results

The reader will recall that the problem with which this study was concerned is three-fold. It was of interest to determine: (1) if S-R relationships will affect the efficiency of an S-R-R ensemble when the R-R relationships are held constant, (2) if the R-R relationships will affect the efficiency of an S-R-R ensemble when the S-R relationships are held constant, and (3) if there are interactive affects between the stimulus conditions and the response conditions.

Three different measures were taken to test these hypotheses. The first of these, total adjustment time, was a measure of the time expiring between the presentation of the signal and the alignment of the mechanical stylus on the correct point of the ten-by-ten matrix. The second measure, Response Latency, was a measure (for each respective crank) of the time expiring between the presentation of the signal and production of a crank movement great enough to release the hinge latch ($\frac{1}{2}$-inch movement). The measures of both the total adjustment time and crank latency were recorded to the nearest 1/100th second. For the third measure, direction of initial crank movement, E simply recorded the direction, either left or right, that the lever had been tripped by the crank movement.

The analysis of each of these three measures will be discussed in turn.

Total Adjustment Time

The first step in the analysis of these data was the grouping of measures for each subject and each session according to Response Condition (CC-CC, CC-C, C-CC, or C-C) and Stimulus Type (Digital, Pictorial, or Instructional). The measures were then summed across the nine replications of each Response Condition within each stimulus series and means computed from these sums. These means provided the basic data and the corresponding analysis of variance for all further analysis of total adjustment time. A summary of these data for Sessions One, Two, and Three are shown in Tables 4, 5, 6, 7, 8, and 9, respectively.

Analysis By Session. -- A two-way analysis of variance was applied to the data of each respective session.

Inspection of Tables 5, 7, and 9 show that similar results were obtained for all three sessions. In all sessions, the F ratio for Stimulus Types was found to exceed the .01 significance level. In no case did the F ratios for

Table 4. Total adjustment time by response condition and stimulus type. (Session one)

Stimulus type	Subjects	Response Conditions 1	2	3	4	Sum and mean
Digital	1	917	888	968	835	
	2	623	667	585	539	
	3	829	776	760	846	
	4	734	588	582	621	
	5	576	600	572	570	
	6	635	543	589	626	
	Sum	4314	4062	4056	4037	16,469
	Mean	719	677	676	673	686
Pictorial	1	644	708	874	812	
	2	769	748	749	625	
	3	643	642	731	589	
	4	565	544	559	579	
	5	580	640	625	557	
	6	655	562	651	554	
	Sum	3856	3844	4189	3716	15,605
	Mean	643	641	698	619	650
Instructional	1	757	808	945	821	
	2	877	1027	927	805	
	3	957	797	852	972	
	4	953	1024	1037	958	
	5	811	850	694	944	
	6	924	852	860	783	
	Sum	5279	5358	5315	5283	21,235
	Mean	880	893	886	880	885
Sum for response conditions		13,449	13,264	13,560	13,036	53,309
Mean " " "		747	737	753	724	740

Table 5. Results of two-way analysis of variance for total adjustment time. (Session one)

Source of variation	SS	df	MS	F	p
Stimulus Types	766,085	2	383,043	39.73	< .01
Response Conditions	8,767	3	2,922	.30	----
ST x RC	20,969	6	3,495	.36	----
Subjects	220,692	5	44,138	4.58	< .01
Residual	530,296	55	9,642		
Between Groups	795,821	11	72,347		
Within Groups	750,988	60	12,516		
Total	1,546,809	71			

Table 6. Total adjustment time by response condition and stimulus type. (Session two)

Stimulus type	Subjects	Response 1	Conditions 2	3	4	Sum and mean
Digital	1	553	629	703	563	
	2	469	583	535	460	
	3	489	518	556	521	
	4	496	571	543	512	
	5	427	429	420	392	
	6	604	501	574	549	
	Sum	3038	3231	3331	2997	12,597
	Mean	506	538	555	499	525
Pictorial	1	681	627	620	651	
	2	517	550	515	469	
	3	534	599	646	675	
	4	473	471	500	487	
	5	384	375	408	388	
	6	652	511	656	541	
	Sum	3241	3133	3345	3211	12,930
	Mean	540	522	557	535	539
Instructional	1	751	881	790	639	
	2	803	740	780	830	
	3	762	701	751	728	
	4	737	647	793	777	
	5	656	741	660	714	
	6	659	552	605	641	
	Sum	4368	4262	4379	4329	17,338
	Mean	730	710	730	721	722
Sum for response conditions		10,647	10,626	11,055	10,537	42,865
Mean " " "		591	590	614	585	595

Table 7. Results of two-way analysis of variance for total adjustment time (Session two)

Source of variation	SS	df	MS	F	p
Stimulus Types	583,588	2	291,794	6.16	$<.01$
Response Conditions	8,878	3	2,959	.63	----
ST x RC	8,302	6	1,384	.29	----
Subjects	197,212	5	39,442	8.33	$<.01$
Residual	260,380	55	4,734		
Between Groups	600,768	11	54,615		
Within Groups	457,592	60	7,626		
Total	1,058,360	71			

Table 8. Total adjustment time by response condition and stimulus type. (Session three)

Stimulus type	Subjects	Response 1	2	Conditions 3	4	Sum and mean
Digital	1	496	565	593	507	
	2	467	510	508	453	
	3	478	472	490	460	
	4	471	408	418	426	
	5	380	435	428	400	
	6	550	496	578	544	
	Sum	2842	2886	3015	2790	11,533
	Mean	474	481	502	465	481
Pictorial	1	545	590	568	549	
	2	477	488	477	465	
	3	472	483	553	452	
	4	446	427	410	418	
	5	322	321	361	337	
	6	488	434	475	473	
	Sum	2750	2743	2844	2694	11,031
	Mean	458	452	474	449	460
Instructional	1	701	610	635	671	
	2	699	680	639	659	
	3	704	642	645	693	
	4	608	547	637	630	
	5	578	518	509	745	
	6	738	534	628	544	
	Sum	4028	3531	3693	3942	15,194
	Mean	671	588	615	657	633
Sum for response conditions		9620	9160	9552	9426	37,758
Mean " " "		534	509	531	524	524

Table 9. Results of two-way analysis of variance for total adjustment time. (Session three)

Source of variation	SS	df	MS	F	p
Stimulus Types	431,402	2	215,701	98.63	$<.01$
Response Conditions	7,912	3	2,637	1.21	----
ST x RC	24,671	6	4,112	1.88	----
Subjects	152,199	5	30,440	13.92	$<.01$
Residual	120,260	55	2,187		
Between Groups	463,985	11	42,180		
Within Groups	272,459	60	4,540		
Total	736,444	71			

Response Conditions or the interaction between Stimulus Types and Response Conditions reach the .05 level of confidence.

The variance due to differences among Ss was computed only so it could be removed from the Within Groups variance, thus providing a more sensitive error term. It is of only incidental importance that all Subject F ratios proved to be significant at or beyond the .01 level of confidence.

Duncan's Multiple Range Test (1955), for the testing of significance of difference among means, was applied to the Stimulus Type means of each respective session. The results of these analyses are shown in Table 10. In order for the difference between two means to be significant at or above the .05 level of confidence, it must equal or exceed the adjacent values enclosed in parentheses. All differences which equal or exceed these values are marked with an asterisk.

An inspection of Table 10 shows that once again, similar results were obtained for the three sessions. In all cases the mean adjustment time for the Instructional stimulus was found to be significantly greater than the mean adjustment time for either the Digital or the Pictorial stimulus. In no case, however, did the difference between the mean adjustment time of the Digital and Pictorial stimuli approach the .05 level of significance.

From the results of these data one can feel confident in concluding that for any given session: (a) the Instructional stimulus results in adjustment times that are significantly greater than those resulting from either the Digital or the Pictorial Stimuli. The adjustment times for the latter two, however, do not differ significantly from one another. (b) Total adjustment time is not differentially affected by the four Response Conditions. (c) There are no interactive effects occurring between the Stimulus Types and Response Conditions, i.e., each Stimulus Type affects the Response Conditions in essentially the same way.

Table 10. Tests for significance of difference among stimulus type means. (Sessions one through three)

Session One

Stimulus Type	$\bar{X}$	$\bar{X}$-650	$\bar{X}$-686
Instructional	885	235* (59.72)	199* (56.71)
Digital	686	36 (56.71)	
Pictorial	650		

Session Two

Stimulus Type	$\bar{X}$	$\bar{X}$-525	$\bar{X}$-539
Instructional	722	197* (41.83)	183* (39.73)
Pictorial	539	14 (39.73)	
Digital	525		

Session Three

Stimulus Type	$\bar{X}$	$\bar{X}$-460	$\bar{X}$-481
Instructional	633	173* (28.46)	152* (27.03)
Digital	481	21 (27.03)	
Pictorial	460		

Over-All Analysis. -- An inspection of the raw data suggested that a pooling of the three sessions might bring out trends not found in the foregoing analysis, and the similarity of results for the three sessions insured that this pooling was legitimate.

In order to obtain the best estimate of the over-all effects due to Stimulus Types and to Response Conditions, it was necessary to remove the variance due to sessions. This was accomplished by pooling the sums of squares for sessions and then applying a two-way analysis of variance for heirarchal data. This analysis permits the break-down of the pooled sum of squares and thus the specification of the variance due to sessions, the variance due to the independent variables (Stimulus Types and Response Conditions), and variance due to independent variable by sessions interaction.

The results of this analysis and the subsequent application of Duncan's Multiple Range Test to the Stimulus Types means are shown in Tables 11 and 12 respectively. Tables 11 and 12 show that the results of the over-all analysis mirror those found in the analysis of individual sessions. As was previously found, the *F* ratio for Stimulus Types exceeds the .01 probability level and the *F* ratio for both Response Conditions and for ST by RC interaction fail to reach the .05 level of significance.

Both the ST by Sessions and RC by Sessions interaction, which are found only in the over-all analysis, fail to reach the .05 level of significance. On the basis of these nonsignificant *F* ratios for interaction one can feel confident in concluding that practice (sessions) does not have differential affects on either Stimulus Types or Response Conditions.

It becomes obvious that no new insight or trends are brought out by the over-all analysis. The conclusions resulting from the analysis of individual sessions apply equally well to the over-all analysis.

Table 11. Results of two-way analysis of variance for total adjustment time. (Over-all analysis)

Source of variation	SS	df	MS	F	p
Stimuli Types: Sessions	1,781,075	6	296,846		
Stimuli Types	1,741,351	2	870,676	157.70	< .01
Stimuli x Sessions	39,724	4	9,911	1.80	>.05
R. Conditions: Sessions	25,557	9	2,840		
Response Conditions	17,479	3	5,826	1.06	>.05
Response Condition x Sessions	8,078	6	1,346	.24	>.05
Interaction: Sessions	53,942	18	2,997	.54	>.05
Subjects : Sessions	510,103	15	38,007		
Residual : Sessions	910,936	165	5,521		

Table 12. Test for significance of difference among stimulus type means. (Over-all analysis)

Stimulus Type	$\bar{X}$	$\bar{X}$-550	$\bar{X}$-564
Instructional	747	197* (44.30)	183* (42.02)
Digital	564	14 (42.02)	
Pictorial	550		

Individual Analyses. — Finding no difference in the total adjustment time for the four Response Conditions was unexpected. Inspection of the data suggested the possibility that the four Response Conditions could be differentially effective for a given S, but because of individual differences in set or stereotype, differences among Response Conditions were obscured by pooling subjects. A separate analysis was therefore conducted for each individual S. For the sake of brevity the raw data for each S have not been included.

The results of a two-way analysis of variance applied to the data of each S is shown in Table 13. A significant F ratio is found for Stimulus Types in all six cases. A subsequent application of Duncan's Multiple Range Test to the Stimulus Type means showed that, for every S, the Instructional Stimulus resulted in a significantly greater total adjustment time than for the other two Stimulus Types. As was found in the previous analyses, no differences were found between the Digital and the Pictorial stimuli.

A significant F ratio for Response Conditions was found for only one S (S No. 6 in Table 13). An application of Duncan's test to the means for Response Conditions (see Table 14) resulted in the finding that the mean for Condition 1 (CC-CC) was significantly greater than the mean for Condition 2 (C-CC). Although none of the remaining combinations proved to be significant, the mean for Condition 1 (CC-CC) was very nearly enough larger than the mean for Condition 4 (CC-C) to reach significance; and the mean for Condition 3 (C-C) was very nearly enough larger than the mean for Condition 2 (C-CC) to reach significance.

It was only S Number Five who showed a significant F ratio for ST by RC interaction $[P(F \geq 3.84) < .01]$. The ST x RC F ratio for the remaining five S's did not even approach the .05 level of significance. This is the first

Table 13. Results of two-way analysis of variance for total adjustment time. (Individual subjects - three sessions)

Source of variation	SS	df	MS	F	p
	Subject #1				
Stimulus Types	56,889	2	28,445	4.65	< .05
Response Conditions	31,403	3	10,467	1.71	----
ST x RC	11,818	6	1,969	.32	----
Sessions	372,133	2	186,067		
Residual	140,690	23	6,117		
	Subject #2				
Stimulus Types	457,474	2	228,737	75.27	< .01
Response Conditions	26,765	3	8,922	2.94	----
ST x RC	4,822	6	804	.26	----
Sessions	256,870	2	128,435		
Residual	69,908	23	3,039		
	Subject #3				
Stimulus Types	201,213	2	100,607	21.10	< .01
Response Conditions	10,955	3	3,652	.77	----
ST x RC	15,560	6	2,593	.54	----
Sessions	301,010	2	150,505		
Residual	109,674	23	4,768		
	Subject #4				
Stimulus Types	585,173	2	292,586	59.66	< .01
Response Conditions	4,781	3	1,594	.33	----
ST x RC	1,959	6	327	.07	----
Sessions	354,735	2	177,367		
Residual	112,789	23	4,904		
	Subject #5				
Stimulus Types	490,136	2	245,068	125.03	< .01
Response Conditions	10,001	3	3,334	1.70	----
ST x RC	45,116	6	7,519	3.84	< .01
Sessions	326,263	2	163,132		
Residual	45,085	23	1,960		
	Subject #6				
Stimulus Types	143,016	2	71,508	13.14	< .01
Response Conditions	54,233	3	18,078	3.32	< .05
ST x RC	9,497	6	1,583	.29	----
Sessions	105,186	2	52,593		
Residual	125,209	23	5,444		

evidence found which suggests that different Stimulus Types affect Response Conditions in different ways.

Table 14. Test for significance of difference among means for response conditions (Subject number six)

Response Condition	$\bar{X}$	$\bar{X}$-554	$\bar{X}$-584	$\bar{X}$-624
1	656	102* (76.72)	72 (74.75)	32 (71.06)
3	624	70 (74.75)	40 (71.06)	
4	584	30 (71.06)		
2	554			

The fact that only a single significant F ratio was found for ST by RC interaction and a single significant F ratio found for Response Conditions make interpretation of these data somewhat difficult. A total of thirty F ratios were computed for the six subjects, so, on a probability basis one could expect 1.5 F ratios to reach the .05 level of significance from chance alone. On the other hand, one could interpret these results as being due to individual differences in amount of personal stereotype.

Further mention will be made of these results in a later section of this paper.

Response Latency

The reader will recall that a separate measure of the response latency was obtained for both the right-hand and the left-hand cranks. It was reasoned that a great deal of unnecessary detail and confusion would be avoided if it were possible to pool the data rather than submit the data for each hand to a separate analysis. A preliminary analysis (a two-way analysis of variance applied to the two sets of data) resulted in identical results for the two hands. It also seemed obvious from a cursory examination of the data that the two measures were highly correlated. Thus, it appeared statistically legitimate to pool these data.

A second factor that required consideration was the bearing that pooling or not pooling would have on the problem under investigation. Because this study was designed to test two-hand performance, the knowledge that the two hands had different latencies (as they did) or that they react differently to different Stimulus Types or Response Conditions, has little bearing on the problem at hand since it would not appear that such differences reflect differences in encoding processes. It seems much more meaningful, therefore, to consider the two hands as a single functioning unit. For the abovementioned reasons it was decided to pool the two measures for the succeeding analyses. The data in Tables 15 and 16 are made up from these pooled values.

As was the case with Total Adjustment Time, the pooled latency measures were grouped, for each S and each session, according to Response Condition and Stimulus Types. The measures were then summed across the nine replications of each response condition within each stimulus series and means computed from these sums.

In order for the present analysis to be consistent with the method of analysis used for Total Adjustment Time, the following analyses would have to be made: an over-all analysis (pooling the three sessions), an analysis by sessions (Ss pooled), and an individual analysis. However, because of the extreme similarity of results that were previously obtained for the three sessions, it was reasoned that this analysis could be excluded.

Over-All Analysis. — The same statistical techniques that were applied to the data for Total Adjustment Time were again applied to the data for Response Latency, viz., a two-way analysis of variance with the subsequent application of Duncan's Multiple Range Test for those cases where a signi-

Table 15. Pooled response latency by response condition and stimulus type (Over-all analysis)

Stimulus type	Subjects	Response 1	2	Conditions 3	4	Sum and mean
Digital	1	737	776	678	685	
	2	291	327	304	327	
	3	376	369	368	353	
	4	308	329	329	311	
	5	376	422	433	392	
	6	420	447	486	397	
	Sum	2508	2670	2598	2465	10,241
	Mean	417	445	433	411	427
Pictorial	1	656	686	645	665	
	2	303	294	314	304	
	3	311	302	306	325	
	4	267	282	270	285	
	5	345	332	372	351	
	6	410	398	431	381	
	Sum	2292	2294	2338	2311	9,235
	Mean	382	382	390	385	385
Instructional	1	1341	1242	1319	1281	
	2	664	739	941	737	
	3	842	944	1070	997	
	4	749	818	781	808	
	5	838	942	894	951	
	6	668	775	820	642	
	Sum	5102	5460	5825	5416	21,803
	Mean	867	910	971	903	909
Sum for response conditions		9902	10,424	10,761	10,192	41,279
Mean " " "		550	579	598	566	573

Table 16. Results of two-way analysis of variance for pooled response latency. (Over-all analysis)

Source of variation	SS	df	MS	F	p
Stimulus Types	4,064,535	2	2,032,268	276.39	<.01
Response Conditions	22,023	3	7,341	1.00	----
ST x RC	26,246	6	4,374	.59	----
Sbbjects	1,420,897	5	284,179		
Residual	404,393	55	7,353		
Between Groups	4,112,804	11	373,891		
Within Groups	1,825,290	60	30,422		
Total	5,938,094	71			

ficant F ratio was noted.

The summary data and the results of the analysis of variance are shown in Tables 15 and 16 respectively. Table 16 shows that the only F ratio to reach significance ($P < .01$) was that for Stimulus Types. The results of Duncan's Multiple Range Test (see Table 17) show that the Instructional stimulus resulted in response latencies which were significantly greater than those for either the Digital or the Pictorial stimuli, but with no significant differences between the latter two Stimulus Types.

Table 17. Test for significance of difference among stimulus type means. (Over-all analysis)

Stimulus Type	$\bar{X}$	$\bar{X}$-385	$\bar{X}$-427
Instructional	573	188* (52.15)	146* (45.52)
Digital	427	42 (45.52)	
Pictorial	385		

It is obvious that the trend that has persisted throughout the analysis of Total Adjustment Time again appears in the results for Response Latency. So, rather than providing for new insights, the data for Response Latency simply verified the conclusions drawn from the over-all analysis of Total Adjustment Time.

Individual Analyses. -- Summaries of analyses of variance applied to the response latencies of individual Ss are shown in Table 18. It will be noted that these results are nearly a mirror image of those found in the individual analysis of total adjustment time. A significant F ratio was found for Stimulus Types for all six Ss. Duncan's Multiple Range Test showed that, for all six Ss, the Instructional stimulus resulted in response latencies which

Table 18. Results of two-way analysis of variance for response latency. (Individual subjects - three sessions)

Source of variation	SS	df	MS	F	p
		Subject #1			
Stimulus Types	342,764	2	171,382	93.19	< .01
Response Conditions	399	3	133	.07	----
ST x RC	8,262	6	1,377	.75	----
Sessions	68,036	2	34,018		
Residual	42,312	23	1,839		
		Subject #2			
Stimulus Types	189,982	2	9,499	15.32	< .01
Response Conditions	5,256	3	1,752	2.83	----
ST x RC	9,302	6	1,550	2.50	----
Sessions	5,341	2	2,670		
Residual	14,262	23	620		
		Subject #3			
Stimulus Types	347,887	2	173,944	157.70	< .01
Response Conditions	2,776	3	926	.84	----
ST x RC	7,451	6	1,242	1.13	----
Sessions	20,405	2	10,203		
Residual	25,379	23	1,103		
		Subject #4			
Stimulus Types	216,612	2	108,306	77.69	< .01
Response Conditions	614	3	205	.15	----
ST x RC	530	6	88	.01	----
Sessions	46,531	2	23,266		
Residual	32,053	23	1,394		
		Subject #5			
Stimulus Types	250,133	2	125,006	316.63	<.01
Response Conditions	1,549	3	516	1.31	----
ST x RC	2,098	6	350	.89	----
Sessions	21,515	2	10,757		
Residual	9,080	23	395		
		Subject #6			
Stimulus Types	82,043	2	41,021	58.02	<.01
Response Conditions	6,791	3	2,264	3.20	.05
ST x RC	2,917	6	486	.69	----
Sessions	14,814	2	7,407		
Residual	16,252	23	707		

were significantly greater than those for the Digital or the Pictorial stimuli. All Ss but S Number Five showed no differences between the latter. It was found for S Number Five, however, that the response latencies for the Digital stimuli were significantly greater than those for the Pictorial stimuli.

The only additional F ratio to reach significance ($P < .05$) was for Response Conditions in the case of S Number Six. Duncan's Multiple Range Test showed that Condition 3 (C-C) resulted in response latencies which were significantly greater than those for Condition 4 (CC-C). No other significant differences were found.

It will be noted that it was also S Number Six who showed a significant Response Conditions F for Total Adjustment Time. One would expect, from observing the great amount of similarity in the results of Total Adjustment Time and Response Latency, that the Response Condition that resulted in the greatest adjustment time would also result in the greatest response latency and vice versa. This, however, was not the case. Reference to Table 14 shows that for Total Adjustment Time, Condition 1 (CC-CC) was significantly greater than Condition 2 (C-CC). This can be contrasted with the results for Response Conditions where it was found that Condition 3 (C-C) was significantly greater than Condition 4 (CC-C). This could be taken to mean that the two measures are measuring different phenomenon. However, one could have little confidence in this conclusion since the difference was found for only one S.

Direction of Initial Crank Movement

The reader will recall that the direction of the initial movement of each respective hand was recorded for each trial. When considering the direction of the two movements in combination, each set would necessarily correspond with one of the four Response Conditions. For example, if the direction of the initial movement for the left-hand were clockwise and the direction of the initial movement for the right-hand were counter-clockwise, the set would classify as Response Condition 2 (C-CC).

Frequency Distribution. -- The first step in the analysis of these data was the compilation, by Stimulus Type and by Subject, of a frequency distribution for the four Response Conditions. The next step was the computation of a Heterogeneity Chi Square from the data of each S to test the null hypothesis that the frequency of occurrence of the four Response Conditions was randomly distributed.

The frequency distribution (pooled over sessions) and the resulting Chi Square values are shown in Table 19. There are four types of Chi Square values shown in this table, viz., a Chi Square for Stimulus Types, a Total Chi Square, a Pooled Chi Square, and a Heterogeneity Chi Square. A significant Chi Square value for Stimulus Types indicates that the cell frequencies, for that particular Stimulus Type, deviate significantly from the hypothetical. (If all movements were correctly performed, or if the Response Conditions were randomly distributed, each cell would contain a frequency of twenty-seven.) The Total Chi Square in this analysis was not tested for significance since the only reason for its computation was to facilitate computation of the Heterogeneity Chi Square. A significant Pooled Chi Square value indicates that, on the average, there is a predominating tendency toward deviation with a common sign. The Heterogeneity Chi Square tells one whether this deviation is consistent from stimulus to stimulus.

Examination of the Chi Square values located along the right-hand border of Table 13 shows that, by and large, there is a great deal of deviation from the hypothetical ratios but with little consistency from Stimulus Type to Stimulus Type. It will be noted that four Ss (Numbers 2, 3, 5, and 6) show

Table 19. Frequency distribution and chi square values for initial movements.

Subject	Stimulus Type	Response Condition 1	2	3	4	Chi Square Values		p
1.	Digital	33	21	15	39		34.29	< .01
	Pictorial	14	40	25	29		12.82	< .01
	Instructional	24	21	26	27		1.70	----
						Total	38.81	
						Pooled	6.44	----
						Heterogeneity	32.37	< .01
2.	Digital	47	7	40	14		77.91	< .01
	Pictorial	42	10	43	13		35.77	< .01
	Instructional	44	9	44	11		42.88	< .01
						Total	156.56	
						Pooled	119.68	< .01
						Heterogeneity	36.88	< .01
3.	Digital	20	33	33	22		5.40	----
	Pictorial	15	58	22	13		49.11	< .01
	Instructional	16	40	36	16		18.22	< .01
						Total	72.73	
						Pooled	54.31	< .01
						Heterogeneity	18.42	< .01
4.	Digital	19	26	33	30		4.70	----
	Pictorial	25	24	37	22		4.97	----
	Instructional	18	32	36	19		9.30	< .05
						Total	18.97	
						Pooled	13.42	----
						Heterogeneity	5.55	----
5.	Digital	58	20	13	17		48.36	< .01
	Pictorial	42	25	19	22		11.78	< .01
	Instructional	13	66	22	6		80.85	< .01
						Total	140.99	
						Pooled	48.75	< .01
						Heterogeneity	92.24	< .01
6.	Digital	46	29	12	21		23.18	< .01
	Pictorial	39	29	11	29		15.11	< .01
	Instructional	28	43	20	17		15.03	< .01
						Total	53.32	
						Pooled	37.83	< .01
						Heterogeneity	15.49	< .05

Total - 9 df
Pooled - 3 df
Heterogeneity - 6 df

all six Chi Square values to be significant beyond the .01 level. One can conclude from these results that certain of the Response Conditions were used significantly more often than others but the tendency to use a given Response Condition more (or less) frequently than another did not persist from Stimulus Type to Stimulus Type. Evidently, for a given S, the Response Condition that was used most frequently varies with the particular stimulus type that is used. Examination of the cell frequencies in Table 19, however, shows that there is little consistency from S to S.

The remaining two Ss (Numbers 1 and 4) show somewhat different trends. For S Number One, neither the distribution for the Instructional stimulus nor the distribution for the pooled data differ significantly from that which could be expected by chance. These data indicate that although there are significant deviations for the Pictorial and the Digital stimuli, these deviations do not persist after the Stimulus types have been pooled. The significant Heterogeneity Chi Square is further evidence that the deviations are not consistant from Stimulus Type to Stimulus Type.

The opposite trend is found for the data of S Number Four. It can be seen that the only Stimulus Type to result in a significant Chi Square was the Instructional, and this Chi Square value was significant at only the .05 level. However, when the Stimulus Types are pooled a significant Chi Square is found ($P < .01$). The non-significant Heterogeneity Chi Square indicates that there is consistency in the deviations from Stimulus Type to Stimulus Type. It appears that this S, unlike the remaining five, does not show a Stimulus Type x Response Condition interaction.

Number of Correct Initial Movements. — A tabulation was made of the number of correct initial movements (by Stimulus Type and by Response Condition) which were made by each S. By correct initial movement is meant a movement

Table 20. Number of correct initial movements by response condition and stimulus type.

Stimulus type	Subjects	Response Conditions 1	2	3	4	Sum and mean
Digital	1	12	5	1	3	
	2	14	5	5	1	
	3	5	10	9	6	
	4	6	3	9	13	
	5	11	6	5	9	
	6	15	2	12	3	
	Sum	63	31	41	35	170
	Mean	10.50	5.16	6.83	5.83	7.08
Pictorial	1	7	8	4	6	
	2	14	8	5	0	
	3	2	13	6	6	
	4	10	6	11	10	
	5	5	9	7	10	
	6	13	2	15	2	
	Sum	51	46	48	34	179
	Mean	8.50	7.67	8.0	5.67	7.46
Instructional	1	10	12	3	3	
	2	1	15	2	2	
	3	5	10	8	6	
	4	6	9	12	2	
	5	7	5	4	5	
	6	16	3	13	2	
	Sum	45	54	42	20	161
	Mean	7.50	9.0	7.0	3.33	6.71
Sum for response conditions		159	131	131	89	510
Mean " " "		8.83	7.28	7.28	4.94	7.08

Table 21. Results of two-way analysis of variance for number of correct initial movement.

Source of variation	SS	df	MS	F	p
Stimulus types	3	2	1.5	.09	----
Response Conditions	137	3	45.67	2.73	----
ST x RC	101	6	16.83	1.01	----
Within Groups	1002	60	16.70		
Between Groups	241	11	21.91		
Total	1243	71			

which, if continued, would move the stylus to the correct target without reversing the direction of rotation for either crank.

A summary of these data are shown in Table 20. When pooled over three sessions there is a total of 108 movements for each Stimulus series and 27 movements for each cell in the table. A cursory examination of Table 20 will show that the number of correct initial movements vary from 0 to a maximum of 16 correct out of 27 with an overall average of 7.08. Such a low frequency of correct movements is surprising.

These data were submitted to a two-way analysis of variance, the summary of which is shown in Table 21. It will be noted that the summary of this analysis differs from those previously presented in that the Subject variance has not been included. It was found in a preliminary analysis that the variance for Ss was so small that its removal from the Within Groups variance and the subsequent loss of degrees of freedom made a less sensitive test, i.e., decreased the size of the F ratio and consequently the significance level.

It will be noted that the F ratio for Response Conditions was the only one that approached significance ($10 > P < .05$), which is due to a tendency for Condition 4 to result in fewer correct initial movements than Conditions 1, 2, and 3. There appear to be only small differences among the latter three conditions. Although the non-significant F for ST by RC interaction is consistent with previous results, the non-significant F for Stimulus Types is new.

Discussion

It was hypothesized in an earlier section that the efficiency of a dual control mechanism of the type used in this study would be effected by the stimulus-response relationships, the response-response relationships, and an interaction between the stimulus-response and the response-response relationships, i.e., an S-R-R interaction. The main concern, however, was with the possible effects of the response-response relationship and those of the S-R-R interaction since a good deal is already known about the effects of stimulus-response compatibility.

The results of this study showed that the efficiency of the ensemble, as measured by Total Adjustment Time and Response Latency, was significantly affected by the particular Stimulus Type that was used. The finding that the Instructional Stimulus Type resulted in significantly poorer performance than that for the Digital and Pictorial was expected, since it appeared intuitively that the former requires a greater amount of encoding. The failure to find significant differences between the Pictorial and Digital stimuli was unexpected but has very little bearing on the main problems of this study.

Of much greater interest was the almost complete lack of response-response compatibility effects. The efficiency of this ensemble was, for five of the six Ss, as great with one Response Condition as with another. These results seem to be in conflict with the principles given by workers in the field of time and motion analysis that were discussed in an earlier section (Barnes, 1958). According to these principles, motions should be made in opposite and symmetrical directions. Thus, Condition 2 (C-CC) and Condition 4 (CC-C) should result in more efficient performance than Condition 1 (CC-CC) and Condition 3 (C-C). It is evident that for these five Ss it made little difference to the right-hand what the left-hand was doing and vice versa.

Some support, though rather weak, is given the time and motion principles by the one S who showed a significant F ratio for Response Conditions (S number six). The resulting mean total adjustment time in milliseconds for the four Conditions placed in rank order are as follows: Condition 1 (656 msec.), Condition 3 (624 msec.), Condition 4 (584 msec.), and Condition 2 (554 msec.). Although the only significant difference found was that between Condition 1 and Condition 2, there is a fairly extensive break between Conditions 3 and 4. On the basis of time and motion principles one would expect this difference to be significant. At any rate, the rank order conformed with these principles.

This S's performance as measured by Response Latency shows even less correspondence with the time and motion principles. The means for these data, in milliseconds, ranked from low to high, are: Condition 3 (193 msec.), Condition 2 (180 msec.), Condition 1 (166 msec.), and Condition 4 (157 msec.). Only the difference between Condition 3 and Condition 4 proved to be significant ($P < .05$). Although this difference conforms with the time and motion principles, the expected ranking of Conditions 2 and 3 are reversed. It is difficult to explain the difference in the ranking of the means for Total Adjustment Time and Response Conditions. It seems logical to expect a high correlation between the two.

One interpretation that might be given for these results is that the response-response effects, while important in highly repetitious tasks, are too small to be of any consequence in situations where S is required to make a discrete response in which encoding is required. If this speculation were verified by future research, it would certainly have important implications.

Attention will now be turned to the implications of the data for direction of initial movement. The reader will recall that a frequency count by S and a subsequent Chi Square Test showed that certain of the Response Conditions were used significantly more frequently than others in making the initial movement. A significant Heterogeneity Chi Square indicated, however, that for five of the six Ss, the Response Condition that was used most (or least) frequently varied from Stimulus Type to Stimulus Type. Analysis of the number of correct initial movements showed that there were no significant differences among the Stimulus Types. The differences among Response Conditions were great enough, however, to produce an F ratio which approached the usual criterion for statistical significance ($P < .05$).

It is obvious from these data that there were response sets in operation. These response sets, however, varied from S to S and from Stimulus Type to Stimulus Type. It is interesting to note that in spite of the rather extreme response sets that were in operation, there were no corresponding differences in Total Adjustment Time for the four conditions. Apparently when S responded with a "wrong" initial movement, a greater adjustment time did not necessarily result. This result suggests that the nature of the apparatus made it possible for S to reverse his movement so rapidly that the total adjustment time was not affected. Although somewhat of an ad hoc contribution, it appeared to E that Ss were responding with little regard to the direction of movement specified in the Stimulus. It is possible that a response of any kind whether right or wrong, would provide information faster than the thought processes (or "encoding processes") necessary to "reason out" the direction the cranks should be moved in order to make a correct response. These "reflex type" movements occurred even though the Ss were instructed that both speed and accuracy would be considered in evaluating their performance.

This has interesting implications for future research. It would be interesting to determine what would be the effects on Total Adjustment Time and Response Latency if the Ss were instructed that errors could not exceed five percent of all responses.

The fact that response sets were found but with no corresponding effects on Total Adjustment Time or Response Latency raises an important question. Is one to take the evidence of response sets alone as being evidence for compatibility? Some writers have used the concepts "set," "stereotype," and "compatibility" interchangeably. Fitts et al., (1959), however, have stated that the three concepts refer to three different phenomena, and that the two former (sets and stereotypes) are factors which affect the latter. This implies that an ensemble for which an S has a positive set would necessarily be a compatible one; and a compatible system is obviously a system that is more efficient than an incompatible system. One can see that this reasoning is in conflict with the present results. It appears reasonable to assume that set and compatibility are two different and not necessarily interacting phenomena. It is on the basis of this reasoning that the evidence for response sets has not been taken as conclusive evidence for the existence of R-R or S-R-R compatibility effects in this task.

Thus it was concluded that no evidence for R-R or S-R-R compatibility was found. It is possible that this finding was a function of the particular experimental arrangement that was used and that with a different arrangement and with different and (or) more sensitive measures, these effects might appear. It would at least appear that R-R and (or) S-R-R effects are not as prominent as S-R effects. Establishing the existence and subsequent importance of these effects is a problem that would warrant future research.

Summary

The present study was designed to investigate the following problems: (1) When the relationship between two responses is held constant, does varying the relationship between the stimulus and response have an effect on the efficiency of a system (S-R Compatibility)? (2) When the relationship between the stimulus and response is held constant, does varying the relationship between two simultaneous responses effect the efficiency of an ensemble (R-R Compatibility)? (3) Are there interactive effects between the stimulus and the control conditions (S-R-R Compatibility)?

A two-hand cranking task was used in which S could, by manipulating two cranks, adjust a mechanical stylus to any one of one hundred points on a ten-by-ten matrix. The right-hand crank moved the stylus in the horizontal plane while the left-hand crank moved the stylus in the vertical plane. Each crank could be turned in either a clockwise or a counter-clockwise direction. The four possible combinations of direction of movement of the two cranks made up four Response Conditions, viz., CC-CC, C-CC, C-C, and CC-C.

Six male Ss responded to a stimulus which was projected on the rear side of a translucent screen located approximately 14 degrees below eye level and directly in front of S. Each S proceeded through the three series on each of three consecutive days. The order of the series was completely counterbalanced over Ss and sessions.

Measurements were taken of time required to make a complete adjustment, the latency of the initial response, and the direction of initial movement. For analyses, these measures were grouped according to Response Condition and Stimulus Type.

Two-way analyses of variance and, in those cases where the F ratio reached or exceeded the .05 level of significance, the application of Duncan's Multiple Range Test, showed that the speed of both total adjustment and initial response was dependent upon the particular Stimulus Type used, but was not dependent upon Response Conditions.

A Heterogeneity Chi Square showed that some Response Conditions were used significantly more frequently than others in making initial movements. The favored Response Condition(s), however, varied from Stimulus Type to Stimulus Type and from S to S. These were interpreted as Response Sets.

The existence of Response Sets with no corresponding affect on the over-all efficiency of the system was interpreted to mean that "sets" and "compatibility" were two different phenomena.

On the basis of these data it was concluded that:

1. S-R effects are relatively important in determining the efficiency of this system.
2. No evidence for R-R or S-R-R compatibility has been shown in this study.
3. The results may be a function of the particular experimental arrangement.
4. Further research is needed before the above mentioned results may be generalized.

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ON RESPONSE-RESPONSE COMPATIBILITY

by

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2. No evidence for R-R or S-R-R compatibility has been shown in this study.
3. The results may be a function of the particular experimental arrangement.
4. Further research is needed before the above mentioned results may be generalized.