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THE PRESENCE OF A DUAL PERCEPTUAL SET FOR CERTAIN PERCEPTUAL-MOTOR TASKS

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ABSTRACT

Two independent groups of 24 female college students acted as subjects in an experiment using a single, compensatory pursuit task. One group used a knob control; the other, a lever. In both studies, the zero position of the pointer and the motion relation between pointer and control were varied. Time-on-target performance scores were measured with the pointer in a 12 or a 6 o'clock zero position and with the direction of movement of the pointer and control either agreeing or disagreeing. The pointer dial and the control were aligned vertically in the same plane; the arc of pointer movement was considerably less than 45 degrees on either side of the zero position. The major conclusions drawn were that 1) performance is affected by an interaction between the pointer position and the pointer-control motion relation, 2) subjects behave as if they perceive the rotary mechanical movements both linearly and curvilinearly, 3) the "motion agreement principle" operates in both perceptual sets and performance is a result of the effects of both sets combined.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
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Directorate of Research

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I INTRODUCTION

This is the third of a series of papers designed to study the complex interactions among configurational arrangements of four components generally found in many perceptual-motor tasks. These components are the indicator (the figure), the dial (the background), the control, and the motion relation between indicator and control.

In the first paper, Fitts and Simon (5)(6) found that performance on a dual pursuit task was affected by the interaction between the position of the pointer and the arrangement of the dials. Simon (17), in a second study, found performance was affected significantly by the interaction between the position of the pointer and the location of a lever control in a single pursuit task. The present study was designed to discover the effect of varying the position of the indicator and the motion relation between the indicator and the control on a single pursuit task.

The Motion Relation Problem

The theoretical importance of the motion relation problem becomes more apparent after examining the reviews of the growing psychological literature in this field of research (3)(16). Its practical importance is demonstrated in a survey by Fitts and Jones (4) who found that 17% of pilot errors in flight resulted from turning the controls in the wrong direction in response to a visual cue. Classically, the motion relation problem is inherent in every perceptual-motor study in psychology and represents one of the most universal aspects of behavior -- that of eye-hand coordination.

Controls and indicators may move either in a straight or a curved line. The present paper is concerned with tasks where both components move in a rotary manner. In designing a machine, it is generally accepted that we should use the dominant motion relation between the indicator and control (3)(16). This has been called the "motion agreement principle" (8). A dominant motion relation is one in which the indicator moves in the same direction as the control is turned; when the indicator moves in the opposite direction that the control is turned, the motion relation is a non-dominant one. The present paper attempts to show the ambiguity of the phrase "in the same direction" and to suggest a means of more rigidly defining "direction" so that prediction of man-machine performance is more reliable. Is direction simply a function of the mechanical construction of the apparatus, or is it in part related to the manner in which the subject perceives the movements?

Two Ways of Perceiving the Same Movements

Following a series of studies on discrete tasks, Warrick (22) concluded that a "clockwise-clockwise" hypothesis expressed the dominant motion relation between an indicator and rotary control. This hypothesis, stated simply, is that the operator behaves as if he expects a clockwise movement of the control to result in a clockwise movement of the indicator, and a counterclockwise movement of the control to result in a counterclockwise movement of the indicator. Implicit in the "clockwise-clockwise" hypothesis is the assumption that subjects do perceive the movements they see or impart as rotary, or with a curvilinear set. But it is also conceivable that subjects approach the problem with a linear set, i.e. they perceive directions as right, left, up, and down even on apparatus where rotary indicators and controls were used. In a report from the Special Devices Center (1) it was pointed out that "an 'open window' dial may be perceived as a linear display or a segment of a circular display, which in turn may affect the way in which the operator perceives the movement." Thus, the "clockwise-clockwise" hypothesis is a somewhat limited principle as a guide in the design of equipment for it represents only the dominant curvilinear set. A linear set may also have a dominant or non-dominant motion relation. The more general application of the "motion agreement principle" can occur only when we understand the principles which determine the subjects' perception of the direction of movement -- whether it be with a linear or a curvilinear set, for the response under both of these sets need not be identical for all instrument-control configurations.

Interpreting Earlier Studies by Hypothesizing a Linear Set

The possible existence of a linear set in the motion relation problem involving rotary controls has a bearing on the interpretation of results of a number of studies. The significant differences in performance which occur between equipment using 12 o'clock and 6 o'clock pointer positions might actually be explained as an effect of the relation between the indicator movement and the control movement if it were assumed that the subject actually perceived the movements of the components with a linear set, i.e. in terms of left-right movements (6). Just how this might occur is illustrated in Figure I.

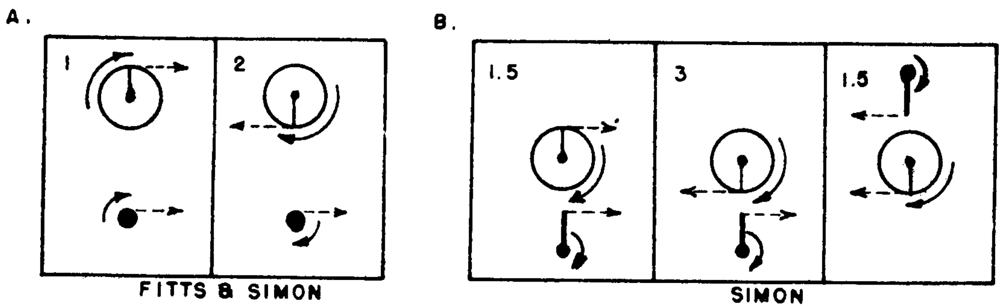

FIGURE I

Direction of movements of indicators and controls as perceived with linear and curvilinear perceptual sets in two experiments. The solid arrow represents the motion relation when the curvilinear set is maintained; the dotted arrow represents the motion relation when the linear set is used. The numbers in the upper left hand corners represent the rank orders of performance on that configuration in each experiment.

Figure I-A illustrates two of the indicator-control configurations operated by one hand in the dual pursuit task presented to subjects by Fitts and Simon (5)(6). In every case, the knob is turned clockwise.[1] The same representations are used in Figure I-B, which shows three of the configurations used in Simon's (17)

1/ Warrick had found that "operators consistently respond as if they expect the indicator to move in the same direction as that portion of the knob adjacent to the indicator" (21,p.2) when a simulated linear indicator was used. Thus the direction of movement of the knob control with a linear set has been represented from the top of the knob in these studies.

earlier study. The rank performance for the configurations in each experiment is shown. The results of these experiments showed a lower performance score when there was a disagreement between the direction of movement of the indicator and control as perceived by a linear set; the construction of the apparatus did not permit any disagreement when perceived with the curvilinear set. We might therefore hypothesize, post facto, that subjects in these experiments behaved as if they were influenced by a linear set.

The Present Study

However, these earlier studies were not designed to study effects of two perceptual sets on the motion relation problem as it has been presented here for although the motion relation as perceived by the linear set was changed from dominant to non-dominant, the mechanical motion relation (curvilinear set) was never varied. Instead, the dominant clockwise-clockwise relation was always used. Similarly, Fitzwater (7) and others (9)(16) varied the mechanical curvilinear motion relation, but did not simultaneously vary the motion relation reflecting the linear set. The present study provided an opportunity to compare the performance of subjects on tasks where both linear and curvilinear motion relations were varied, requiring the subject to perform on a task under both sets with a dominant and a non-dominant motion relation between the indicator and control.

The specific hypotheses to be tested were:

1) There would be a significant interaction between the position of the pointer and the relation between the direction of pointer and control movements as they affect performance on a single pursuit task.

2) Even when the mechanical movements are curvilinear, subjects may behave as if they perceive the movements as linear.

3) Where linear and curvilinear perceptual sets lead to opposing responses, subjects tend to behave as if they are responding more to the linear set.

II APPARATUS

The compensatory pursuit apparatus used in these studies has been described in detail by Grether (11) and briefly in the first paper of the series (17). A motor driven cam turning at the rate of two revolutions per minute transmits fluctuations to a differential gear to which the movements of a control shaft are also transmitted. The output of the differential is the difference between these two inputs and is relayed to the instrument dial located approximately eighteen inches above the control shaft where it appears as a pointer deflection. By properly compensating for the movement of the cam, the subject is able to hold the pointer within the designated target area. The lobes of the cam were so designed that the cam movement alone never deflected the pointer more than 22½ degrees on either side of the target mark, nor more than 45 degrees when combined with the normal movements imparted by the subject.

In the first of the two experiments, a two-inch rotary knob was used as a control. In the second, a twelve-inch lever was used. The dial could be rotated in both experiments so that the zero position of the pointer was either at the 12 o'clock or the 6 o'clock position. The motion relation between the movement of the pointer and the control could be reversed, i.e. in order to move the pointer clockwise, the control was turned clockwise[1] or to move the pointer clockwise, the control was turned counterclockwise[2]. These relationships, which are curvilinear, refer to the mechanical movements of the components and not to the psychological sets of the subjects.

Subjects were seated so that their eyes were approximately 28 inches away from the black instrument panel in which the dial was centered. Four lights in the corner of the panel provided non-glare illumination giving an apparent brightness of thirty-foot lamberts.

Subject's time-on-target was recorded by chronoscopes in thousandths of a minute. A sequence timer controlled the work and rest periods, automatically turning off the cam at the proper times.

1/ To be represented in the future as C-C (clockwise-clockwise).

2/ To be represented in the future as C-CC (clockwise-counterclockwise).

III SUBJECTS

Two groups of 24 female college students were used as subjects. All were right handed, had normal vision with or without glasses, and had never operated a compensatory pursuit task before. One group performed the experiment with the knob control; the other, with the lever control.

The subjects' sex should have no effect on the conclusions drawn from the study. Simon (17) had found that although females' time-on-target performance was at a significantly lower level than that of males on the single pursuit task, the correlation of mean scores on 16 indicator-pointer combinations between male and female subjects was .93, which was as high as the correlations between two male groups. At no time was there a significant interaction between sex and pointer position at any control position.

IV EXPERIMENTAL DESIGN AND PROCEDURE

Two independent experiments were run; they differed only in the type of control used on the pursuit task. In the first experiment, designated Experiment K, a knob control was used. In the second experiment, Experiment L, a lever control was used. Different subjects ran each experiment.

Two conditions of each of two variables were used: the 12 and 6 o'clock pointer positions and the C-C and C-CC mechanical motion relation. Each subject operated the single compensatory pursuit task on each of the four combinations of these conditions. These configurations are 12 C-C, 12 C-CC, 6 C-C, and 6 C-CC.

These four configurations enabled comparisons to be made in performance when the motion relation of one or the other, both, or neither of the perceptual sets -- linear or curvilinear -- is dominant, i.e. the movement of the indicator and control agree as perceived by the specific set. These are shown in Table I and Figure II.

FIGURE II

Motion relations between the indicator and control on four configurations as perceived with a linear and curvilinear set

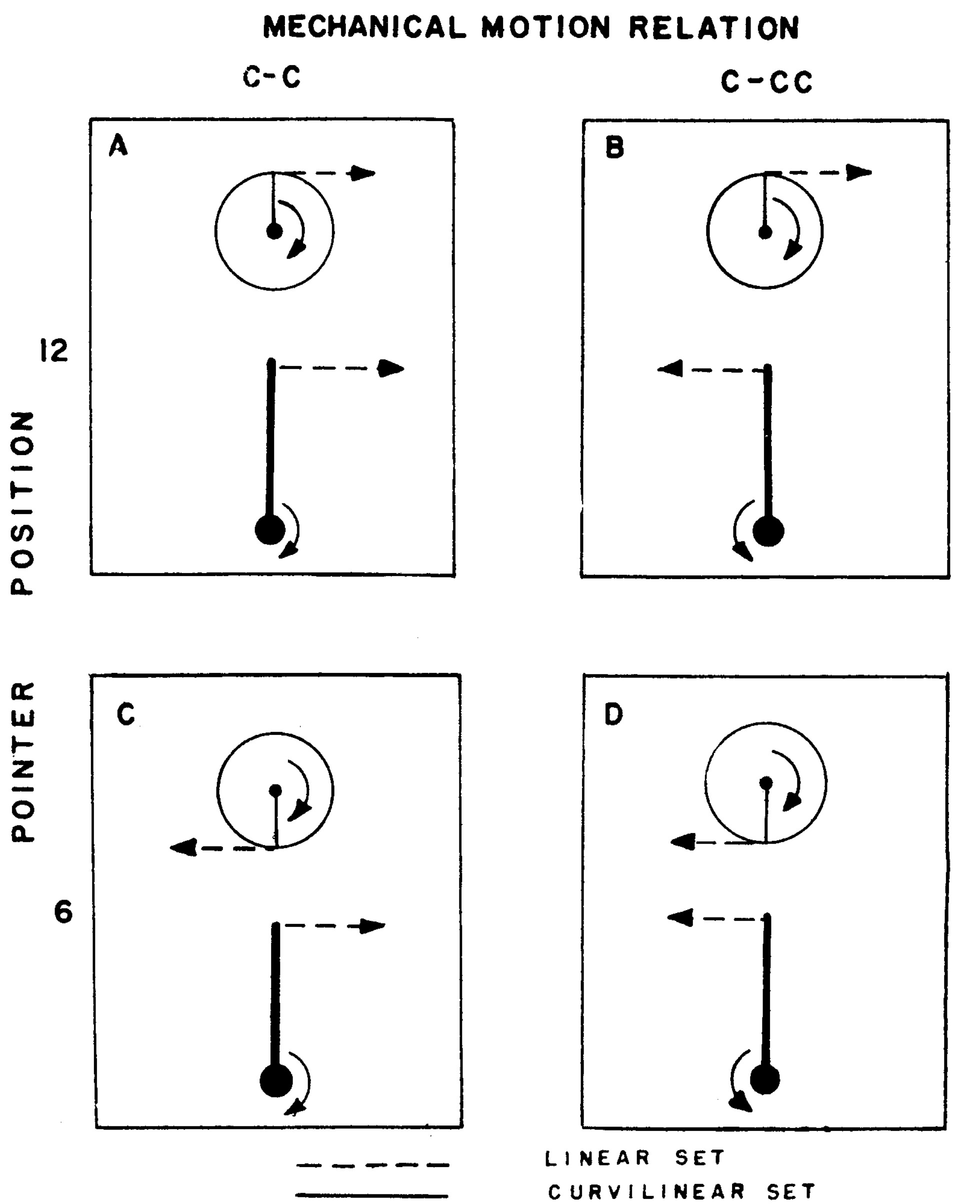

TABLE I

Apparatus configurations and the motion relation as perceived by each set.

	Pointer Position	Mechanical Motion Relation	Perceptual Set	
			Linear	Curvilinear
A)	12	C-C	Dominant	Dominant
B)	12	C-CC	Non-Dominant	Non-Dominant
C)	6	C-C	Non-Dominant	Dominant
D)	6	C-CC	Dominant	Non-Dominant

Subjects were instructed to keep the pointer on the target and were given an opportunity to operate the control and pointer a number of times when the cam was not rotating. They were then given four groups of ten 30-second trials on each condition, each trial being followed by a 15-second rest period. Following the tenth trial, when the pointer position or the motion relation was changed, subjects were given 2½ minutes of additional rest. At this time it was suggested that they study the motion relation between pointer and control if they wished, though no indication as to what the relationship might be was given to them by the experimenter. A warning buzzer sounded one second before each new trial would begin.

Scores for each trial were recorded in thousandths of a minute. Subjects were told their scores after each trial.

At the end of the experiment, each subject was asked which of the four configurations she preferred and why. Since subjects were likely to be biased by their knowledge of scores, the question was worded: "We know what you actually did best on, for we have your scores. But we'd like to know which of the four conditions felt the best to you? If you had your choice of using one of the four conditions, which would you prefer? Which did you like second best? Least of all?" No attempt was made to force a decision from those subjects who failed to notice differences. Since explanations of preference usually involved some reference to a motion relation, care was taken to have the subject demonstrate her preference on the apparatus in order to avoid the ambiguity of the "motion agreement principle".

V RESULTS

Interactions

On both Experiment K and Experiment L, each subject's score on each configuration was obtained by averaging his scores on ten trials. Means and sigmae of the 24 subjects' average score on each of the four conditions are shown in Table II. Table III shows the result of the analyses of the variances of the data.

The results of both experiments verify the first hypothesis that there is a significant interaction between the pointer position and the mechanical motion relation between pointer and control. Testing the major variables by the significant interaction variance, the obtained F values were not significantly greater than that which could be attributed to the interaction. However, these statistical interpretations must be modified by a logical examination of the data, when one considers the types of interactions found in the two experiments.

In Experiment L, the rank orders for the mechanical motion relation scores with a particular pointer position is the reverse of the ranks obtained with the pointer position. In Experiment K, however, the ranks remain the same but the magnitude of the differences between motion relation scores vary. Thus, in the second type of interaction, recommendations for a motion relation in Experiment K could still be the same for either pointer position. An examination of the t-values between conditions better demonstrate what the F test, as it is described above, does not adequately

TABLE II

Means and sigmae of the four configurations in Experiments K and L *

Experiment K

Motion Relation		Pointer Position 12	6	Mean of Motion Relation
C-C	M	184.0	167.0	175.5
	σ	18.0	20.4	
C-CC	M	143.0	151.0	147.0
	σ	24.4	22.6	
Mean of Pointer Position:		163.5	159.0	

Experiment L

Motion Relation		Pointer Position 12	6	Mean of Motion Relation
C-C	M	164.0	140.0	152.0
	σ	27.6	24.4	
C-CC	M	130.0	144.0	137.0
	σ	23.0	25.3	
Mean of Pointer Position:		147.0	142.0	

* Highest score best.

TABLE III

Analyses of variances for Experiments K and L

Experiment K

Source of Variation	D.F.	Variance	F
Pointer Positions	1	546.3	-- *
Mechanical Motion Relation	1	18,956.3	-- *
Interaction PP x MR	1	3,687.7	18.0**
Subjects	23	1,249.9	6.1**
Residual	69	203.3	

Experiment L

Source of Variation	D.F.	Variance	F
Pointer Positions	1	539.2	-- *
Mechanical Motion Relation	1	5,730.5	-- *
Interaction PP x MR	1	8,116.2	48.6**
Subjects	23	2,026.4	12.1**
Residual	69	166.9	

* Not significant below the .05 p level when tested by the interaction variance.

** Significant below the .001 p level when tested by the residual variance.

reflect. The t-values between all the combinations of the conditions for both Experiment K and L are given in Tables IV and V respectively. The residual variance was considered the best estimate of variance for any group and was used to compute all of the standard errors of the mean differences.

From the table of t's it can be seen that in both experiments superiority of performance with the 12 or 6 o'clock pointer position depends on the motion relation with which it was paired. This exemplifies the interaction. However, the picture is somewhat different with the differences between motion relations. In Experiment K, performance on all configurations with the C-C motion relations are statistically superior to those with C-CC motion relations as shown by the t's in Table IV. Furthermore, examination of the scores made by the 24 subjects in the Knob Experiments reveals that with the 12 o'clock pointer all 24 subjects did better on the C-C motion relation and with the 6 o'clock pointer position, 20 did better and only four did better with the C-CC motion relations. X^2 values for both of these are statistically significant below a .001 p level. One can conclude with little doubt that there is a superiority of the C-C motion relation over the C-CC when a knob control was used in this task.

In the Lever Experiment, the t-tests in Table V do not consistently favor the C-C motion relation. Also 23 out of 24 did better with the C-C motion relation when the 12 o'clock pointer position was used, but only eleven out of 24 did better when the 6 o'clock pointer position was used. Thus, when the lever control is used, whether performance with a particular motion relation is statistically superior to another still depends on the pointer position with which it is paired.

Perception of Linear and Curvilinear Sets

So far, our results have been discussed on the basis of the mechanical motion relation between instruments and controls. In order to properly interpret our data in the light of the second and third hypotheses, the results of Table II were analyzed in a different way.

At the beginning of this paper, the conversion of the rotary mechanical movements of the indicator and pointer into terms descriptive of the subject's perceptions or set were discussed.

TABLE IV

Values of t for mean differences between configurations in Experiment K ***

	12 C-C	12 C-CC	6 C-C
12 C-CC	9.83*		
6 C-C	4.17*	-5.66*	
6 C-CC	7.99*	-1.84	3.81*

TABLE V

Values of t for mean differences between configurations in Experiment L ***

	12 C-C	12 C-CC	6 C-C
12 C-CC	9.09*		
6 C-C	6.22*	-2.87**	
6 C-CC	5.42*	-3.67*	- .80

* $p < .01$ (23 d.f.)

** $p < .05$ (23 d.f.)

*** Negative values indicate the mean performance for a configuration on the ordinate is higher than that along the abcissa.

With a curvilinear set, the movements could be perceived by the subjects as they actually are -- clockwise and counterclockwise. With a linear set, the mechanical movements could be perceived as left and right (or up and down). As in the case of the mechanical motion relation, under either set the direction of perceived movement of indicator and control may agree or disagree with each other, i.e. there is a dominant and non-dominant motion relation for each set. The differences in the motion relation between indicator and control under both sets can be compared. If one can assume that the "motion agreement principal" still operates and the dominant motion relation is superior to the non-dominant, then the differences between motion relations should be significant for those perceptual sets which do influence performance. For those sets which do not influence performance, the differences between motion relations should not be significant.

The mean performance scores made with each configuration combined so as to show the mean scores made for dominant and non-dominant motion relations for the two perceptual sets are shown in Table VI. The scores under the curvilinear set are a duplicate of the scores in Table I where the motion relation variable referred to the mechanical movements of the rotary parts.

Actually, the analyses in Table VII is quite similar to the analyses in Table II, except that the sources of variation involving motion relations are renamed in psychological rather than mechanical terms. Thus, "Between Mechanical Motion Relations" is equivalent to "Between Motion Relations with a Curvilinear Set" and the "Interaction between Pointer Positions and Mechanical Motion Relations" is equivalent to "Between Motion Relations with a Linear Set". These two, plus the "Between Pointer Positions" variance represents the three major variables in a Graeco-Latin 2x2 design. This design does not permit the analysis of the interactions between the major variables; the residual variance is used to test all conditions. An examination of Table VI shows that in both experiments under both perceptual sets, the performance scores for the dominant motion relations (C-C or R-R) were superior to scores for the non-dominant motion relation (C-CC or R-L). In other words, when the direction of movement of the indicator agreed with the direction of movement of the control, performance was superior when perceived with either set. Table VII shows that in both experiments these differences between motion relations were statistically significant with both perceptual sets.

TABLE VI

Mean performance scores under dominant and non-dominant motion relations for both perceptual sets*

Experiment K

Pointer Position	Curvilinear Set: Motion Relation C-C	Curvilinear Set: Motion Relation C-CC	Curvilinear Set: Means of Pointer Position	Linear Set: Motion Relation R-R	Linear Set: Motion Relation R-L	Linear Set: Means of Pointer Position
12	184.0	167.0	175.5	184.0	143.0	163.5
6	143.0	151.0	147.0	151.0	167.0	159.0
Means of Motion Relation:	163.5	159.0		167.5	155.0	

Experiment L

Pointer Position	Curvilinear Set: Motion Relation C-C	Curvilinear Set: Motion Relation C-CC	Curvilinear Set: Means of Pointer Position	Linear Set: Motion Relation R-R	Linear Set: Motion Relation R-L	Linear Set: Means of Pointer Position
12	164.0	140.0	152.0	164.0	130.0	147.0
6	130.0	144.0	137.0	144.0	140.0	142.0
Means of Motion Relation:	147.0	142.0		154.0	135.0	

* The mechanical motion relation was always rotary.

TABLE VII

Analysis of variances for Experiments K and L

Experiment K

Source of Variation	D.F.	Variance	F
Between Pointer Positions	1	546.3	2.7
Between Motion Relations with a Curvilinear Set (C-C vs C-CC)	1	18,956.3	93.2*
Between Motion Relations with a Linear Set (R-R vs R-L)	1	3,687.7	18.1*
Between Subjects	23	1,249.9	6.1*
Residual	69	203.3	

Experiment L

Source of Variation	D.F.	Variance	F
Between Pointer Positions	1	539.1	3.2
Between Motion Relations with a Curvilinear Set (C-C vs C-CC)	1	5,730.5	34.3*
Between Motion Relations with a Linear Set (R-R vs R-L)	1	8,116.2	48.6*
Between Subjects	23	2,026.4	12.1*
Residual	69	166.9	

* $p < .001$

These results indicate that subjects perform as if both the linear and curvilinear sets are operating simultaneously. That is to say, subjects behave not only as if they perceive the movements to be curvilinear, which would be natural with rotary indicators and controls, but also linear, as hypothesized.

Linear versus Curvilinear Sets

Although the above analysis indicates that the subject performs as if both perceptual sets are operating, it does not answer the question as to which set would dominate if the dominant response under each set leads to opposing responses. This can be answered by examining the results from performance with the 6 o'clock pointer position and the two mechanical motion relations. Configurations "C" and "D" of Table I and Figure II illustrate two configurations which when operated under the two perceptual sets, results in a conflict of the dominant responses. Thus, in Configuration "C", Table I, we see the direction of movement of the indicator and control agree when perceived by a curvilinear set but not by the linear. The reverse is true for Configuration "D". If Configuration "C" yields a higher performance score than "D", this indicates the curvilinear set influences behavior more strongly than the linear. If the performance score on "D" is higher than "C", then the linear set is the stronger of the two.

In Table VIII, the mean performance scores are shown for these conditions when both the knob and the lever control are used. Table IX gives the results of an analysis of the variances of the four conditions. The variance between controls was tested by the variance between subjects using the same control. The variances between the mechanical motion relations as well as the interaction of control and motion relation were tested by the pooled subject variances. This analysis was necessary since part of the scores were correlated (between motion relations) and the remainder were uncorrelated (between controls). The results from Tables VIII and IX indicate that performance with a knob control is significantly superior to that with a lever control. This was found by Simon (17) in an earlier experiment. On the other hand, differences between motion relations were not significant without considering the type of control used.

From a re-examination of the appropriate t's in Table IV and V, it can be seen that Configuration "C", in which the curvilinear set is dominant, was significantly superior to "D" when a knob control

TABLE VIII

Mean performances on tasks with knob and lever controls, dominant and non-dominant motion relations, and all pointers in a 6 o'clock position

		Control		Means of Motion Relations
		Knob	Lever	
Mechanical Motion Relations	C-C *	167.0	140.0	153.5
	C-CC **	151.0	144.0	147.5
	Means of Controls:	159.0	142.0	

TABLE IX

Analyses of variances of Experiments K and L combined using only the 6 o'clock pointer position

Source of Variances	D.F.	Variance	F
Between Controls	1	6,929.2	7.47 ***
Between Subjects using same control	46	927.2	--
Between Mechanical Motion Relations	1	993.3	--
Interaction of Control x MR	1	2,107.5	13.38 ****
Pooled Subjects of Control x MR	46	157.5	--

* This row represent Configuration "C" in Table I and Figure II.

** This row represents Configuration "D" in Table I and Figure II.

*** $p < .01$

**** $p < .001$

was used. When the lever control was used, Configuration "D", in which the linear set is dominant, was slightly but NOT significantly superior to "C". In evaluating these results, it must not be forgotten that the mechanical movements of both controls and pointers were actually curvilinear.

Thus, neither perceptual set was always dominant. Instead, the dominant perceptual set in the conflicting situation depended to some extent on the type of control used.

Subjective Preferences

The subjective preferences of the subjects agreed substantially with their objective scores. The order of preferences for the four configurations in both experiments are shown in Tables X and XI.

Thus in Experiment K, the rank order of preferences for the four configurations was identical with the mean performance scores made on these conditions. The preferred configurations were for those configurations which favored the dominant motion relation with a curvilinear set, i.e. 12 C-C and 6 C-C.

In Experiment L, the first and second preferences were ranked in the same order as the mean performance scores while the order of third and fourth preferences -- although quite similar -- were reversed from the mean performance scores (which were not significantly different). The more preferred configurations in Experiment L were those favoring the dominant motion relation with a linear set, i.e. 12 C-C and 6 C-CC.

In the study using the lever control, not one subject, when asked to explain his preferences, used circular (clockwise and counterclockwise) terms. Fourteen of the 24 subjects actually used descriptive terms of "left" and "right" to describe motion relations between the pointer and the lever. Others would gesture and speak of the "same direction", the gestures generally conveying the impression of a linear, side-to-side motion.

When subjects in the study using the knob control were asked to explain their preferences, seven spoke of the left and right motion relationship, but six also spoke in the clockwise and counterclockwise terms. Thus, even the terminology differed significantly when the type of control was changed.

TABLE X

Number of subjects preferring each configuration while using the knob control

Order of Preference	12 C-C	12 C-CC	6 C-C	6 C-CC
First Preference	14	1	6	2
Second Preference	4	4	4	8
Third Preference	3	6	4	5
Fourth Preference	1	8	5	5
No Preference Stated	2	5	5	4
Mean Preference *: (RANK)	1.6 (1)	3.1 (4)	2.4 (2)	2.6 (3)

TABLE XI

Number of subjects preferring each configuration while using the lever control

Order of Preference	12 C-C	12 C-CC	6 C-C	6 C-CC
First Preference	14	3	0	6
Second Preference	2	1	5	9
Third Preference	4	6	5	1
Fourth Preference	0	7	8	5
No Preference Stated	4	7	6	3
Mean Preference *: (RANK)	1.5 (1)	3.0 (3)	3.2 (4)	2.0 (2)

* Based only on subjects who stated preferences.

VI DISCUSSION

The Effect of Motion Relation on Continuous Pursuit Task Performance

Numerous studies have found the 12 o'clock pointer position superior to other pointer positions (2)(5)(6)(10)(23). The present study has illustrated, however, that the effectiveness of a particular pointer position cannot be predicted without some knowledge of the motion relation between the pointer and the control. Performance with a 12 o'clock pointer is actually poorer than with a 6 o'clock pointer when the mechanical motion relation between it and a rotary control do not agree.

The present study further substantiates the conclusion that a change in the motion relation is important on a continuous task. Although it has generally been agreed that the motion relation between indicator and control affects performance on discrete or discontinuous tasks (19)(20)(21)(22), this fact has been subject to qualifications by some psychologists when applied to continuous tasks. Thus Grether (9) and Mitchell and Vince (16) concluded that it was a relatively unimportant variable. The latter pair wrote: "a one dimensional tracking task differs from the discontinuous task in that the directional relationship is not an important factor in performance" (p. 28). They too, however, discovered that the change in the motion relation significantly affected performance as the task became more complex, as subjects became aware of the change, and when the left hand was used. Fitzwater (7), using the same apparatus as Grether, and applied researchers on aircraft instruments where the motion relation between indicator and control was reversed (8)(12)(13) found that the change does markedly affect performance on the continuous task. The dual-set hypothesis to be presented below, attempts to explain how motion relation changes may actually be operating without any apparent shift in performance levels under certain conditions, i.e. 6 o'clock pointer positions.

A Dual-Set Hypothesis for Perceptual Motion Problems

The "motion agreement principle" states that performance on a perceptual-motor task is superior when the indicator moves in the same "direction" as the control. The results of the present experiment demonstrate that "direction" is partially defined by the particular set with which the subjects perceive the movements of the indicator and control. The hypothesis that with certain perceptual-motor tasks two perceptual sets operate simultaneously to affect performance was supported.

Where the machine components rotate through less than a semi-circle, the direction of movements can be perceived as being linear (left-right or up-down) as well as of being curvilinear (clockwise or counterclockwise). For each set, there is a dominant and a non-dominant motion relation. In the dominant motion relation, the component movements are in the same direction; in the non-dominant, they move in opposite directions.

Rank performance on the four configurations used in these experiments could not be predicted if it were assumed that only one or the other of these perceptual sets were used. It was necessary to assume that both were operating to influence performance. Only when the direction of the control movement could agree with the direction the indicator movement as perceived with <u>both</u> sets did that configuration yield the highest performance. When the direction of control movement was opposite to the direction of indicator movement for <u>both</u> sets, then performance was the poorest for that configuration. On configurations in which the directions of movement of indicator and control agreed as perceived with one set but disagreed as perceived with the other, performance scores fell in between the two extremes, as if the effects of the two perceptual sets tended to summate and partially neutralize each other. It is for this reason that a change from the dominant to the non-dominant mechanical motion relation did not seem to affect performance when a 6 o'clock pointer was used with the 12 o'clock lever.

It cannot be assumed that subjects are consciously aware of the simultaneous operation of two sets; it is only implied that they behaved <u>as if</u> the two exist. However, the mean subjective rank preferences for the four configurations corresponded closely with their mean performance scores on the task.

Nor does the study attempt to answer whether or not both sets operated within the same subject or only within the group (between subjects). However, because the individual subject's performance tended to follow the trend of the group, the simultaneous operation of the two sets appears likely. Of course, as in most behavior, the relative strength of the two sets as they affect performance will be reflected in individual differences.[1]

1/ Simon and Fitts (18) found a tendency for very young subjects to favor a linear set; as the age of the subject increased, there was an increased tendency for the curvilinear set to operate.

Linear Sets with Rotary Mechanical Movements

Why should a linear set be present at all when the mechanical movements are in fact curvilinear? Why should a subject behave as if he perceives rotary movements as straight ones? Several factors may actually facilitate a linear perceptual set.

From the subject's viewpoint, the actual rotary movements of the indicator and control may appear to move linearly because the extent of their movement is limited. If the angle of deflection had been greater than 90 degrees to either side of a zero point, then turning a control to the left would result in a pointer movement to the left when the pointer was in the upper half of the dial and to the right when the pointer was in the lower half of the dial. Thus, in order for the subjects to establish a "law of movement" that was consistent, the subject would be forced to "think" in curvilinear terms. But in the present study and in many applied situations where rotary indicator and control movements are used, the total pointer deflections from zero does not exceed 90 degrees. In this case, thinking in linear (left-right) terms does not lead to contradictory movements between indicator and the control movements and therefore is sufficient to perform the task satisfactorily.

The eyes, tracking the moving pointer, move from left to right and may result in a preference for a linear set. The slight curve of the pointer's movement can be overlooked by the grosser eye movements.

All of the factors involved in deciding whether the linear or curvilinear set will be dominant have not been completely determined. Nothing is known of the effect of up-down movements on the linear set with rotary machine components.

The type of control used does affect which perceptual set was dominant when the two sets conflicted. This may be an effect of the muscles used. The lever, involving gross movements of the large muscles of the arm, is more conducive to the linear (left-right) movement, whereas, the knob, involving more circular movements of the wrist muscles, is more conducive to the curvilinear set.

VII CONCLUSIONS

When the configuration of a single compensatory pursuit task is arranged so that its parts move through a limited arc and the indicator and control are aligned vertically in the same plane, the following conclusions can be drawn:

1. Performance is affected by an interaction between the pointer position and the motion relation between indicator and control.

2. This interaction can be most parsimonously explained by hypothesizing the existence of two perceptual sets -- that the subject sees the rotary mechanical motion both linearly and curvilinearly.

3. Both perceptual sets abide by the "motion agreement principle" and performance seems to result from a summating effect of the two sets. Performance is most superior when the correct response is a dominant one for both sets (12 o'clock pointer, C-C mechanical motion relation), is most inferior when the correct response is a non-dominant one for both sets (12 o'clock pointer, C-CC mechanical motion relation), and falls between these extremes when a response is dominant for one set and non-dominant for the other (6 o'clock pointer - either mechanical motion relation).

4. When the direction of movement of dominant responses to the two perceptual sets conflict, subjects tend to respond more with the dominant response of the curvilinear set with a knob control and with that of a linear set with a lever control on this continuous pursuit task.

5. The rank order of the subjects' mean subjective preferences for particular configurations tended to agree with the rank order of their performance.

6. Subjects tended to prefer configurations favoring the linear set when a lever control was used and the curvilinear set when a knob control was used.

7. Performance is superior when a knob rather than a lever control is used.

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