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EFFECTS OF VISUAL DISTORTIONS ON MOTOR EXECUTION AS MEASURED IN A DRAWING TEST[1]

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Summary.—The influence of visual distortions introduced by cylindrical lenses upon copying a geometric pattern of varying distortion was studied in 15 *Ss*. The experimental conditions specifically influenced shape but not size and regularity of drawings; the latter rather depend upon repetition of the task. The results are discussed as indicating some properties of a central selective mechanism for a visual sensorimotor model.

The nature of visual perception and subsequent motor execution has often been explored by upsetting in some manner the natural interaction between the eye and the visual environment. Such experimentation in man has involved alteration of the visual field through illusions (Ames, 1949) or through lens or prism combinations introduced between the eye and the visual environment (Ames, 1946; Burian, 1943; Helmholtz, 1866; Lippincott, 1917; Smith & Smith, 1962; Stratton, 1897; Wadsworth, 1876). Among the more recent experiments, the work of Held and Gottlieb (1958) and Held and Hein (1958) on human adaptation to visual re-arrangement induced by wedge-prisms has shown again the importance of re-afferent stimulation in perception. Of interest is the information flow model Held proposed to account for the effects of sensorimotor experience upon such adaptation (Held, 1961). Perception and perceptual phenomena are more often being framed in terms of such models (MacKay, 1962). By expanding the dimensions measured in visual sensorimotor experiments, such models may be made more adequate. Thus Held's model, which describes the long-term effects noted in his experiments, is a modification of a model originally proposed by Holst (1954) to describe an instantaneous process (see also Hein & Held, 1962).

To uncover additional factors which might be of use in future information flow models of visual-motor coordination, we have attempted in this pilot study to examine other dimensions of visual perception. The problem initially was to find a task which was more complex than the target localization method of Held and which was at the same time quantifiable; this would make it unlike many of the earlier visual re-arrangement experiments. Such was the drawing test of Reed, *et al.* (1965) for testing motor execution; this task requires copying with pencil on paper a geometric pattern (Fig. 1, A) according to specific instructions; from each copy critical measurements are taken and, with the aid of a com-

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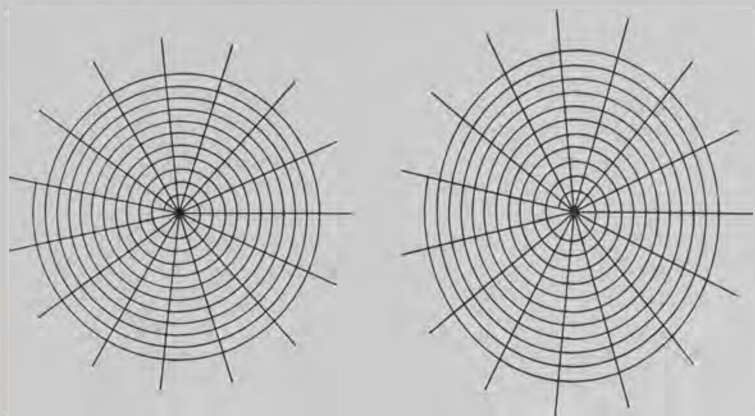
puter, 20 parameters are generated which characterize S's drawing in terms of the dimensions *size*, *shape*, and *regularity*.

In our experiment distortion of the visual field was introduced along the cardinal axes by two means: the model itself was distorted (Fig. 1, B); and S viewed the model or this distortion through six diopter cylindrical lenses oriented along either the vertical or the horizontal axis. In addition to observing the geometric pattern, S was allowed to monitor his own copy while he drew,



A B

FIG. 1. A depicts the "regular" symmetrical model (*RM*); B depicts the "distorted" model (*DM*). Length of radius in the original *RM* was 8.5 cm.

thereby maintaining the intact visual motor feedback. To measure the immediate impact of the introduced visual distortions with as little contamination as possible from long-term exposure to any of the conditions, the test sample for each condition was small, each trial was begun immediately upon presentation of each condition, and the entire experiment was performed in one session for each of the 15 Ss.

METHOD

The procedure was designed to acquaint S with the geometric model and the task under the various test conditions, taking care to minimize effects of training upon subsequent drawings during the actual experiment and to obtain a sample of drawings which was truly representative of S's performance under each condition. Thus the experiment was divided into two phases—a training phase, with one drawing per consecutively presented condition, followed by a testing phase in which a series of five drawings were performed consecutively under each condition. To reduce residual effects of one condition upon another, a 2-min. pause was taken between conditions of the test phase.

By using the symmetrical model (*RM*) or the distorted model (*DM*) with either plano lenses (*PL*), 6 diopter cylindrical lenses oriented along the vertical axis (*DL-vert*), or 6 diopter cylindrical lenses oriented along the horizontal axis (*DL-horiz*), the following 6 conditions were compared: *PL* with *RM*, *PL* with *DM*, *DL-vert* with *RM*, *DL-vert* with *DM*, *DL-horiz* with *DM*, and *DL-horiz* with *RM*. All 6 conditions were presented to each *S* in the same order which originally had been randomly chosen; however, this fixed order was rotated with each succeeding *S* so that only 3 *S*s ever began the experiment under the same condition.

Each of 15 naive, right-handed males, aged 17 to 29 yr., performed the experiment in a single 1.5-hr. session. The setting was a darkened room with 2 small spot lamps directed to discretely illuminate only the model and the drawing area. The model was placed upright about 42 cm. from *S* who drew with pencil on paper upon a smooth horizontal surface. The drawing instructions, which emphasized that *S* was to copy the model "as closely as possible," were given at the start of the training phase and were repeated at the start of each new condition of the testing phase. Each drawing was removed immediately upon its completion.

The models copied (Fig. 1) contain 15 radii drawn from the center outward. Superimposed on the radii is a spiral of 11 complete turns, drawn counterclockwise in one continuous movement from the periphery to the center. To aid in analysis, each model is labelled with regard to the cardinal axes in the following manner: north is at the top, east is to the right, south is at the bottom, and west is to the left of the figure.

Measurements were made on each drawing according to Reed, *et al.* (1965) and fed into an IBM 1620 computer programmed to generate 20 parameters (cf. Table 1) which characterize each drawing in terms of size, shape, and regularity. The *size* of the drawing is represented by the mean length of the radii, the total length of all strokes (radial and spiral) drawn, the "center" area (the area bounded by the innermost spiral turn), the "spiral" area (the area between the innermost and the outermost spiral turn) and the "frame" area (the area between the outermost spiral turn and a line connecting the outermost points of each spoke). The *shape* of the drawing is indicated by the following quotients: the spiral width divided by the spiral length (horizontal diameter of the outermost spiral turn/vertical diameter of the outermost spiral turn), the quotients of radii in the horizontal (west/east) and vertical (north/south) directions. Other shape measures include the standard deviation of the radii, this term expressed as a proportion of the mean radial length ("relative deviation of radial length"), and the standard deviation of the lengths of radii where they are crossed by the outermost spiral. This latter measure is expressed as a proportion of the mean radial length and is termed the "relative deviation of radii" at the outermost spiral turn. *Regularity* of the angles is indicated by the measure "angle regularity" and the standard deviation of central angles; regularity of the spiral is computed for the four cardinal axes. Size and shape are both reflected in the analysis of "mesh" size (the trapezoidal area bounded by two adjacent radii and two adjacent spiral turns). The median of mesh sizes indicates size, and the standard error and widths of mesh sizes indicate regularity.[2]

Results

A three-factor design variance analysis was performed for each parameter after the one described by Winer (1962, p. 172) for one random and two fixed variables. The first drawing made in each condition was omitted from the analysis so as to reduce the influence of the previous condition. Thus in our design there were six conditions (lens-model combinations) and four trials (successive copies), with all 15 *Ss* performing in all combinations. The results of the analyses are shown in Table 1.

Change due to the various experimental conditions was appraised by comparing in a sign test (Siegel, 1956, pp. 68-83) *PL, RM*, which was taken as a control, with each of the other five conditions for those parameters which showed a significant variance ($p = .05$) due to condition. The first two drawings done under each condition were excluded to minimize the residual effects resulting from previous conditions. Median values of the last three drawings in each condition were used in these comparisons because of the small sample size and because of the variability within samples. Significant comparisons ($p < .05$) are shown in Table 2.

To duplicate each lens-model combination as it appeared on *S*'s retina, photographs of *RM* and *DM* were taken through *PL, DL-vert*, and *DL-horiz*, with each model 42 cm. from the lens surface. Analyses were performed so as to characterize each of the 6 resulting photographs in terms of the 20 parameters studied in *S*'s drawings. Thus each condition as it theoretically appeared on *S*'s retina was qualitatively compared with condition *PL, RM* as it theoretically appeared on *S*'s retina. This qualitative comparison is shown in the parentheses of Table 2 alongside *Ss*' actual performance.

For an analysis of change due to successive copying, Drawing 3 was compared with Drawing 5. Here, medians were taken across all 6 conditions for Drawing 3 and for Drawing 5. This procedure was followed since, regarding any one parameter, effects due to condition did not appear to be related to any one particular drawing within the drawing series; rather, the influence of a specific condition, when considering the total subject population, seemed to be spread throughout the series of 5 drawings for that condition. Thus it was as-

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[2]Additional information regarding the program and models may be obtained by writing the author.

TABLE 1

Summary of Analyses of Variance of all Parameters

Parameter	Conditions			Trials			Conditions × Trials		
	df	*MS*	*F*	*df*	*MS*	*F*	*df*	*MS*	*F*
Angle regularity	5	8.25	3.075	3	6.98	4.374*	15	3.87	1.938
SD central angles	5	7.59	1.732	3	4.13	4.672*	15	1.80	1.071
Relative spiral regularity									
north	5	0.02	0.673	3	0.04	5.833†	15	0.01	0.950
east	5	0.17	3.262	3	0.06	4.119	15	0.02	1.360
south	5	0.13	3.738*	3	0.04	4.875*	15	0.02	1.438
west	5	0.02	0.670	3	0.02	2.292	15	0.01	1.196
SE mesh size	5	0.67	3.582*	3	0.04	0.458	15	0.09	1.259
Width/length	5	0.45	7.634†	3	0.00	1.043	15	0.00	0.913
Radius, north/south	5	0.04	1.866	3	0.00	0.089	15	0.01	1.771
Radius, west/east	5	0.04	1.641	3	0.00	0.998	15	0.02	1.789
Total radial length—*SD*	5	11.44	1.451	3	3.77	1.038	15	2.28	0.812
Relative deviation	5	0.00	0.991	3	0.00	2.509	15	0.00	0.738
Rel. dev. of radial length to outer spiral	5	69.59	3.795*	3	26.82	3.370	15	8.31	0.983
Center area	5	487559.60	3.134	3	5025.00	0.195	15	27255.26	0.664
Spiral area	5	26298000.00	1.383	3	22340000.00	3.301	15	3782666.60	0.584
Frame area	5	55016600.00	4.527*	3	7956666.60	2.761	15	3012866.60	1.315
Line length	5	15480.00	0.026	3	1125866.60	8.348†	15	100693.33	1.190
Mean radial length	5	438.86	2.412	3	238.40	6.043†	15	14.01	0.830
Median mesh size	5	6178.44	3.538*	3	1271.00	2.250	15	864.26	1.652
Mesh width	5	1847.06	1.734	3	1103.83	4.666*	15	80.82	0.557

*$p < .01$. †$p < .001$.

TABLE 2

Comparison of *PL*, *RM* With Each Condition

Parameter	Condition				
	A	B	C	D	E
	PL, DM	*DL-vert. RM*	*DL-vert. DM*	*DL-horiz. DM*	*DL-horiz. RM*
Angle regularity	0 (−)	−*(−)	0 (−)	0 (0)	0 (−)
Relative spiral regularity					
south	0 (−)	0 (−)	0 (−)	0 (−)	0 (0)
east	0 (−)	0 (−)	0 (−)	0 (−)	−*(0)
SE mesh size	0 (−)	0 (−)	0 (−)	+†(+)	+*(+)
Width/length	−†(−)	−*(−)	−†(−)	−†(+)	+†(+)
Relative deviation of radial length to outer spiral	0 (+)	0 (+)	0 (+)	0 (+)	0 (+)
Center area	0 (+)	−*(+)	0 (+)	−†(+)	0 (+)
Mean radial length	0 (+)	0 (+)	+†(−)	0 (+)	0 (+)
Median mesh size	0 (−)	+*(−)	0 (−)	0 (+)	0 (+)

*$p < .05$. †$p < .01$.
Note.—0 indicates no change, − indicates decrease, + indicates increase. Theoretical changes taken from photographic measurements are in parenthesis.

sumed that condition effects would not distort effects due to trials. This comparison of Drawing 3 with Drawing 5 was performed on those parameters which showed significant variance ($p = .05$) associated with trials. The data were analyzed using the Wilcoxon matched-pairs signed-ranks test (Siegel, 1956, pp. 68-83). Results are shown in Table 3.

TABLE 3

Comparison of Drawing 3 With Drawing 5

Parameter	Direction of change	*p*
Angle regularity	increase	.01
SD of central angles	decrease	.01
Relative spiral regularity		
north	none	
east	none	
south	none	
Relative deviation of radial length to outer spiral	decrease	.01
Spiral area	increase	.05
Frame area	increase	.05
Line length	increase	.05
Radial length (mean)	increase	.01
Mesh width	increase	.02

The effects of visual distortion upon the regularity, size, and shape of the drawings may be summarized in the following way. The experimental conditions affected the variance of spiral but not angle regularity (Table 1); however,

TABLE 2

COMPARISON OF *PL*, *RM* WITH EACH CONDITION

Parameter	Condition				
	A	B	C	D	E
	PL, DM	*DL-vert. RM*	*DL-vert. DM*	*DL-horiz. DM*	*DL-horiz. RM*
Angle regularity	0 (−)	−*(−)	0 (−)	0 (0)	0 (−)
Relative spiral regularity					
south	0 (−)	0 (−)	0 (−)	0 (−)	0 (0)
east	0 (−)	0 (−)	0 (−)	0 (−)	−*(0)
SE mesh size	0 (−)	0 (−)	0 (−)	+†(+)	+*(+)
Width/length	−†(−)	−*(−)	−†(−)	−†(+)	+†(+)
Relative deviation of radial length to outer spiral	0 (+)	0 (+)	0 (+)	0 (+)	0 (+)
Center area	0 (+)	−*(+)	0 (+)	−†(+)	0 (+)
Mean radial length	0 (+)	0 (+)	+†(−)	0 (+)	0 (+)
Median mesh size	0 (−)	+*(−)	0 (−)	0 (+)	0 (+)

*$p < .05$. †$p < .01$.
Note.—0 indicates no change, − indicates decrease, + indicates increase. Theoretical changes taken from photographic measurements are in parenthesis.

sumed that condition effects would not distort effects due to trials. This comparison of Drawing 3 with Drawing 5 was performed on those parameters which showed significant variance ($p = .05$) associated with trials. The data were analyzed using the Wilcoxon matched-pairs signed-ranks test (Siegel, 1956, pp. 68-83). Results are shown in Table 3.

TABLE 3

COMPARISON OF DRAWING 3 WITH DRAWING 5

Parameter	Direction of change	*p*
Angle regularity	increase	.01
SD of central angles	decrease	.01
Relative spiral regularity		
north	none	
east	none	
south	none	
Relative deviation of radial length to outer spiral	decrease	.01
Spiral area	increase	.05
Frame area	increase	.05
Line length	increase	.05
Radial length (mean)	increase	.01
Mesh width	increase	.02

The effects of visual distortion upon the regularity, size, and shape of the drawings may be summarized in the following way. The experimental conditions affected the variance of spiral but not angle regularity (Table 1); however, a more or less regular spiral can not be associated with any specific lens-model combination (Table 2). Visual distortions produced significant variance also in the size parameters and, in fact, a decrease in center area can be attributed to several of the conditions (Table 2, B, D). Finally, the lens-model combinations affected the shape of the spiral but not of the over-all radial display (Table 1). Table 2 shows that each condition produced a specific change in the spiral shape as measured by the parameter width/length. In sum, although the lens-model combinations influenced the variance of spiral regularity and of some size measures, these measures were not altered in any specific ways by them. The shape of the drawings, as reflected in the parameter width/length, however, was specifically altered by each of the conditions.

Over successive trials there is significant variance in both angle and spiral regularity and in mean radial and line length (Table 1). Table 3 indicates that successive drawing of the model uniformly influences angle, but not spiral, regularity so that angles become more regular with successive copies. Thus successive copying of the model, by itself, affects in some way the regularity of angles between spokes and the size of drawings, while the conditions themselves primarily affect the shape of the spiral.

Discussion

Assume *S* behaves as a sensorimotor system reacting to direct visual and feedback inputs in such a way as to produce a drawing exactly matching the pattern seen on the retina. Let us define this behavior as a direct transformation of perceptual input into motor output. For such a direct transformation of visual input into motor execution, the distorting lenses should not influence the appearance of the final copy. Because *S* observes what he draws as well as the model through the distorting lenses, a drawing of the same size, shape, and regularity as the model would appear to him through these distorting lenses to be just as distorted as the model itself, and in effect *S* would draw the model just as he would see it without the lenses. Sensorimotor models which tie all internal circuits directly to external inputs and which do not include central selection or judgment would predict this type of direct transformation.

Such a direct transformation between visual input and motor execution did not occur in this experiment. Consider, for example, the task of copying the distorted model through distorting lenses; in this situation if there were a direct transformation, *S* should have drawn a distorted model; yet under the experimental conditions *S*'s drawings differed from the symmetrical "undistorted" model for only two or three parameters (Table 2, C, D). Likewise, if *S* directly transformed the distortions he saw into drawing, drawings of the symmetrical model copied through *PL* or through *DL-vert* should have been similar; however, there are differences in drawings produced under these two conditions (Table 3, B).

Three factors could possibly determine the drawings which *S* made of the model when observed through the distorting lenses or through *PL*: the direct visual observation of the model itself, the visual observation of the copy as it was being produced as well as the motor feedback, and finally the subjective bias which colored these other inputs. The nature and influence of the first two factors has been studied, often in detail, by most authors who have been concerned with visual distortion and motor execution (see Smith & Smith, 1962). We are primarily concerned with the third factor, central bias, because it has been relatively unexplored.

There are two lines of evidence which strikingly demonstrate the presence of some central factor in our experiment. First, the variance associated with trials and indeed the consistent change over trials for angle and size parameters indicate that the task of successive drawing itself produced changes in motor output which here was uninfluenced by changes in conditions. Second, drawings of the symmetrical and the distorted model seen through *PL* were quite similar when actually on *S*'s retina the two models differed for every parameter (Table 2, A). We conclude that in addition to the direct visual and feedback information an active process of central bias was critically involved in performance of the task.

At first it might appear that the central bias acts merely to screen incoming sensorimotor signals so that only some components of the task (reflecting shape) were altered with change in condition while the other components (reflecting regularity and size) were independently dealt with regardless of the incoming information. Further consideration of the component shape—as reflected in the parameter width/length—indicates that the action of central bias is more complicated. Fig. 2 indicates width/length schematically: as it actually is in each model, as it probably appeared on the retina, and as *S* drew it for each condition. It is apparent that for this parameter, *S* did not respond uniformly with each change in condition. That is, the way *S* used the incoming information as expressed in his drawing varied with the different changes in condition. When-

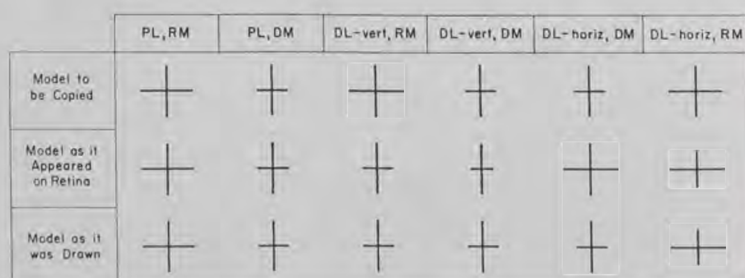

FIG. 2. Width/length (horizontal diameter of outermost spiral turn/vertical diameter of outermost spiral turn) is schematically represented for the model as presented, as it appeared on *S*'s retina and as *S* drew it under the 6 conditions.

ever he copied *DM*, whether through *PL, DL-vert*, or *DL-horiz, S* duplicated *DM*. Indeed, all copies of *DM* were distorted to the same extent. On the other hand, whenever he copied *RM, S* produced a drawing which was distorted along the same axis as the distortion introduced by the lenses. Thus the shape of *S*'s copies of *DM* was the same regardless of the lenses used, while the shape of his copies of *RM* differed markedly with lens differences. For this particular parameter, width/length, *S* directly transformed visual input into motor execution whenever he copied *DM*. However, whenever he copied *RM*, he produced a drawing distorted along the axis of the visual distortion.

We propose that *S* does not directly transform all of what he sees into movement—at least when visual input is a geometric pattern and movement is defined as drawing. The translation of direct visual input and sensorimotor feedback into motor execution is influenced by central processes. The over-all visual environment is screened so that *S* will deal independently with certain aspects of it (in this experiment the dimensions of size and regularity), disregarding condition changes, while for other aspects (here, shape) *S* will consider and respond to condition changes. This latter selected response itself is a complex phenomenon for under certain conditions *S* will directly transform what he sees into movement while under other conditions he will not. We feel that such a differential response to condition change is related to *S*'s capacity to compensate, which in turn is bound up in the nature of the visual cues available to him. Current investigation is directed toward exploring these possibilities.

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