Functional equivalence of masking and cue reduction in perception of shape at a slant

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In a backward masking paradigm Epstein, Hatfield, and Muise (1977) found that presentation of a frontoparallel pattern mask caused the perceived shape of elliptical figures which were rotated in depth to conform to a projective shape function. The current study extended the masking function by examining the effect of a mask which was partially or wholly cotemporal with the target. The study also assessed the functional equivalence of the masking treatment and the conventional treatment for minimizing depth information. Reports of perceived shape and perceived orientation were obtained under three conditions: binocular without mask, binocular with mask, monocular without mask. Under the first condition, perceived shape conformed to objective shape and perceived orientation was proportional to objective orientation. Under the latter two conditions, perceived shape was in very close agreement to projective shape and the two functions did not differ. Orientation was underestimated greatly under both conditions. We concluded that the effect of the mask on perceived shape is mediated by its effect on encoding of orientation information, although an additional effect on the subsequent stage of shape-slant integration cannot be excluded.

Epstein, Hatfield, and Muise (1977) examined the effect of a frontoparallel pattern mask on perception of the shape and the orientation of a family of projectively equivalent elliptical figures which were rotated in depth about the vertical axis. Epstein et al. found that the perceived shapes of rotated figures which were presented for durations sufficient to allow at least 80% shape constancy in the absence of a mask tended to correspond to projective rather than objective shape when presentation of the target figure was followed after an interval of 0-50 msec by a pattern mask. The tendency toward projective shape matches became less pronounced as the interstimulus interval was lengthened. The mask also affected perceived orientation. The orientation of the figures was underestimated considerably, although the effect of the mask on perceived orientation was not as great as the effect on perceived shape.

Epstein et al. (1977) proposed an account of the effects of the mask based on the process of perceiving shape-at-a-slant which is modeled by the shape-slant invariance hypothesis (Beck & Gibson, 1955, Epstein, 1973, 1977, chap. 1; Epstein & Park, 1963; Kaiser, 1967; King, Meyer, Tangney, & Biederman, 1976; Oyama, 1977; Winnick & Rogoff, 1965). It was assumed that the operations suggested by the shape-slant hypothesis are not instantaneous. Registration of projective shape, encoding of orientation and the integration of projective shape and slant information require time. The mask preempts processing and reduces the time available for processing the target. In particular, Epstein et al. proposed that the mask

arrested processing of information about orientation. The effect of the mask on perceived shape was a byproduct of the primary effect on orientation processing.

The present experiment had two objectives: (1) Additional demonstration that masking leads to projective shape masking—Although our earlier experiment demonstrated a clear-cut tendency toward projective shape functions, actual projective shape matches were not observed. In the present study, the temporal arrangement of the target and the mask was modified in an effort to enhance the effectiveness of the mask. Asynchrony of onset (SOA) of the target and mask was shorter than the duration of exposure of the target so that the target and the mask overlapped temporally for the latter part or the whole of the period of target exposure. Moving the mask forward in time should arrest the processing of orientation information still earlier than was the case for the backward masking arrangement of the previous study. Advancing the moment of interruption should lead to greater conformity to projective shape. (2) Demonstration of functional equivalence of masking and depth-cue reduction—We have proposed that the effect of the mask on perceived shape was mediated by its effect on orientation information. This contention would be strengthened by showing that under otherwise identical conditions perceived shape is affected similarly by a mask and by conventional experimental procedures which are known to reduce the number of available orientation cues. Accordingly, in this

experiment, shape and slant-judgments were secured under three conditions: binocular viewing without a mask, binocular viewing with a mask and monocular viewing without a mask. Shape constancy should be high under the binocular no-mask condition, that is, objective shape should be discriminated despite the identity of the projective shapes of the several targets. Also, under this condition, perceived orientation should be proportional to objective orientation. On the other hand, the binocular mask and monocular without-mask conditions should yield projective shape functions and poor discrimination of orientation. Furthermore, the functions for these latter two conditions should be indistinguishable. This outcome would not necessarily entail the conclusion of process equivalence. Nevertheless, functional equivalence suggests that an attempt to establish process equivalence is warranted.

METHOD

Subjects

Six undergraduates participated in the experiment for course credit.

Stimuli

The standard stimuli were six ellipses cut from 1/16-in. white posterboard and affixed to 2½-in.-high black stalks. The edges of the stimuli were beveled to minimize edge cues. The length of the vertical axis in each standard was 5.3 cm. The horizontal axes varied from 3.29 to 15.64 cm. The stimuli were partitioned into two sets, Set 1 consisting of three stimuli having horizontal-vertical axis ratios of .62, 1.00, 1.46, and Set 2 consisting of three stimuli having horizontal-vertical axis ratios of 1.25, 2.03, and 2.95. Each of the shapes within a set was presented at only one orientation, 0° (frontoparallel), 52°, or 65°, respectively. For half of the subjects, the stimuli in Set 1 were rotated clockwise and those in Set 2 were rotated counterclockwise; for the other half, the converse obtained. The objective-shape objective-orientation combinations were such that for binocular viewing all shapes in Set 1 projected a horizontal-vertical ratio of .62 (vertical subtense of 4.5°, horizontal subtense of 2.8°) and all shapes in Set 2 projected a horizontal-vertical ratio of 1.25 (vertical subtense of 4.5°, horizontal subtense of 5.5°) onto the frontoparallel plane.¹ In the monocular viewing condition, the three stimuli of Set 1 had projective shapes of .62, .58, and .52, those of Set 2 were 1.25, 1.17, and 1.12.

The masking stimulus consisted of randomly shaped and randomly arranged pieces of white paper, each less than 1 cm² in size, attached to black matte construction paper. The mask was presented in the frontal plane.

The comparison stimuli for shape were 11 drawings of smaller scale than the standards, each with a vertical axis of 2.2 cm. The horizontal axes varied to produce shapes with horizontal-vertical axis ratios ranging from .45 to 3.8. The shapes were arranged on single sheets of paper in a single column, in either ascending or descending order. Embedded within the 11 comparison shapes were the 6 shapes corresponding to the horizontal-vertical axis ratios of the standard stimuli, one shape narrower than any of the stimuli (ratio of .45), one wider (ratio of 3.8), and four that served as interpolations between the shapes of the first and second stimuli in each set (ratios of .70, .79, 1.46, and 1.61; the comparison shape with a ratio of 1.46 acted both as an interpolation for Set 2 and as a match for Set 1).

The comparison stimuli for orientation were 13 circles (3.0 cm in diameter), each containing a single line drawn along a diameter.

Each drawing represented a top view of the standard shape at one orientation relative to the observer. The represented orientations ranged from 78° counterclockwise through zero through 78° clockwise in 13° increments. The stimuli were arranged on a single sheet of paper in either ascending or descending order. Individual sheets of comparison stimuli were prepared for each trial and placed in a predetermined random order in a looseleaf binder such that only the current trial information was available to the subject. Each comparison stimulus was numbered, and the subject recorded the response by writing its number on a separate index card for each trial.

Apparatus

The apparatus was a modified two-field tachistoscope controlled by an Automated Data System 1248 timer. Illumination was provided by a fluorescent light in each arm, located in front of and below the stimuli. The luminance level in each display field was 3.0 cd/m². Each arm of the tachistoscope was 54 cm long, 23.5 cm wide, and 25 cm high. A lightproof extension of the direct-view channel of the tachistoscope provided access to a calibrated disk into which the standard shapes could be inserted. The axis of rotation for each standard was 68 cm from the viewer's eyes. The masking stimulus was in an extension of the reflected arm of the tachistoscope at the same optical distance as the standard. The subject viewed the stimuli through a 10 × 4 cm window framed by a viewing hood which excluded ambient light and restricted head movement. The viewing field was restricted to the standard and the masking stimulus by occluders appropriately placed in each channel of the tachistoscope. On trials in which the subject viewed the standards monocularly, an additional occluder was placed behind the tachistoscope mirror in such a way that the standard was viewed by the eye for which it would subtend the smaller visual angle. The mask was always viewed binocularly.

Exposure Durations

On all masking trials, the mask was exposed for 400 msec. Exposure durations for the standards varied among subjects from 25 to 75 msec. The SOAs ranged from 0 to 10 msec. These values were selected individually for each subject in the manner explained below. When no mask was presented, offset of the standard was followed by a dark field.

Procedure

A subject served in three 1-h-long sessions, each separated by 24 h. The instructions emphasized phenomenal (apparent) shape and orientation judgments (Carlson, 1977; Epstein, 1963; Epstein, Bontrager, & Park, 1962). The subject was directed to base the response on an immediate impression of shape or orientation. The first session with each subject was devoted to determining the appropriate exposure duration and SOA. We searched for the minimum exposure duration that allowed a high degree of constancy defined as a Brunswik ratio of 0.70 or higher,² and an SOA that, when combined with this exposure duration, yielded a significant masking effect, defined as a mask-induced reduction of the Brunswik ratio by at least .20 from the no-mask level, but would not completely disrupt contour formation. These criteria were met for all subjects.

The following routine determined the desired exposure duration. First there were six trials, one for each standard, at a 500-msec exposure with no mask. Responses to both shape and orientation were elicited on each of these trials. A Brunswik ratio was calculated for the four standards that were rotated from the frontal plane. Another series of six trials at 200 msec with no mask followed and another Brunswik ratio was calculated. These trials familiarized the subject with the procedure and the class of stimuli and helped the experimenter narrow the range of durations to be considered. Two practice trials with the mask, followed by three blocks of 12 trials (6 masked and 6 no-mask trials, randomly interspersed) were then administered. The exposure duration and SOA for the first block was selected on the basis

of the performance on the previous trials at 500 and 200 msec. A duration of 25 msec with SOA of 10 msec on masked trials was most often chosen. Shape judgments were elicited on all of the trials. Orientation judgments were elicited on at least three trials in each block of 12 trials to insure that the subject would not adopt a "shape only" set. At the end of each block, a Brunswik ratio was calculated and the exposure conditions were adjusted recursively to converge to the above mentioned criteria. Whenever ambiguity arose about which stimulus duration to use, the lower exposure duration and briefer SOA were selected. From the data collected during the first session, an exposure duration and SOA were assigned to each subject for use on the 2 subsequent test days. The following values were selected (all values are in milliseconds): Subject 1, exposure 25 with SOA 10; Subject 2, 25 and 5; Subject 3, 25 and 0; Subject 4, 75 and 0; Subject 5, 35 and 0; and Subject 6, 25 and 5.

On the 2 test days, each subject received six practice trials followed by 48 test trials. The test trials comprised two blocks of 24 trials, each consisting of a random permutation of 6 monocular trials (1 trial for each standard), 6 trials of binocular viewing with a mask, and 12 binocular trials without the mask. Since projective shape matching was predicted on the first two sets of 6 trials, 12 binocular trials were presented in order to avoid a situation in which the subject would be expected to repeatedly choose the same comparison stimulus. Both shape and orientation judgments were solicited on every trial, with the shape judgments always reported first. On each day of testing, each subject received a different random permutation of trials.

RESULTS

Shape Matches

Table 1 shows the group mean horizontal:vertical axis ratios of the matches selected by the subjects under the three experimental conditions. The left-hand panels of Figure 1 plot the group means shown in Table 1. Figure 2 presents the data for each of the six subjects individually.

Examination of Table 1 and Figure 1 shows that the experimental treatments produced a large effect in the predicted direction. Under binocular viewing without a mask, the matches conformed closely to the constancy function. The functions for the monocular no-mask condition and the binocular mask condition were alike, but both differed greatly from the constancy function. For these two conditions, the obtained functions resembled projective shape matching. For Set 2, the subjects failed completely to dis-

criminate among the projectively equivalent targets. Inspection of Figure 2 shows that, with the exception of the matches obtained from Subjects 2 and 6 with Set 1, the data for individual subjects conformed to our expectations. In the case of Subjects 1, 3, and 4, the agreement was particularly striking.

An analysis of variance showed a main effect of Set; however, when the scores were transformed into a common scale the effect of Set was not significant. The main effect of Exposure Condition was significant, $F(2,10) = 24.90$, $p < .001$, as was the effect of Shape within Set, $F(4,20) = 18.80$, $p < .001$. The Exposure Condition by Shape within Set interaction was also highly significant. The nature of the interaction is clearly discernible in Figure 1. For shapes in the frontal plane whose projective and objective horizontal:vertical axis ratios are equal, the exposure conditions can have little effect and, indeed, the shape judgments for these combinations of shape and slant were alike under the three conditions. However, as the disparity between objective and projective shape increased, so did the difference between the judgments under the binocular no-mask condition and the other two conditions.

Orientation Matches

Table 2 shows the group mean orientation matches. The right-hand panels of Figure 1 plot the group mean orientation scores after a transformation designed to increase comparability between the shape and orientation scores. The transformed orientation values (TO) result from a nonlinear rescaling of the mean orientation values across subjects. The numerical value of a transformed score represents the shape (horizontal:vertical ratio) that would be compatible with the actual projective shape of the standard involved and the obtained judged orientation in degrees. Thus, for the standard having a horizontal:vertical ratio of .62 and presented in the frontal plane, the transformation is as follows: $TO = .62/\cos\theta$, where .62 is the projective shape of the standard and θ is the obtained orientation score in degrees. As orientation increases from 0° , the denominator in the above formula diminishes at a posi-

Table 1
Mean Ratio of Horizontal to Vertical Axes of Shape Matches Under Three Exposure Conditions

H/V Ratio of Standard		Binocular		Monocular		Mask	
Objective	Projective	Mean	SD	Mean	SD	Mean	SD
Set 1							
.62	.62	.631	.073	.706	.128	.650	.064
1.00	.62	1.043	.266	.778	.164	.874	.342
1.46	.62	1.718	.530	.973	.370	.799	.248
Set 2							
1.25	1.25	1.412	.144	1.523	.238	1.359	.127
2.03	1.25	2.065	.657	1.498	.385	1.436	.229
2.95	1.25	2.830	.822	1.588	.575	1.469	.283

Figure 1. Mean perceived shape (horizontal:vertical axis ratio) and mean transformed perceived orientation as a function of viewing condition. The solid line with slope of 1.0 depicts perfect objective matching; the broken line with slope of zero depicts perfect projective matching. As noted in the description of the stimuli, the three stimuli within each set under the monocular condition actually differed slightly with respect to the projective dimensions, so that the zero slope is an idealized function which disregards these minor fluctuations.

tively accelerated rate. Consequently, the transformation has the effect of compressing the scale for orientation between 0° and about 35°, so that incremental changes in orientation within this range produce relatively small changes in TO. Figure 2 presents the transformed orientation scores for each of the six subjects individually.

Figure 1 shows that the exposure conditions affected judged orientation in the predicted manner. For

binocular viewing without a mask, perceived orientation was roughly proportional to objective orientation. For the mask and monocular conditions, the slope of the orientation function was flatter and, in the case of Set 2, a zero slope was approximated for both conditions. Examination of the individual data presented in Figure 2 discloses great differences between the two sets of standards in the degree to which the subjects conform to the composite picture.

Table 2
Mean Nontransformed Orientation Matches in Degrees Under Three Exposure Conditions

Standard		Binocular		Monocular		Mask	
H/V Ratio	Orientation	Mean	SD	Mean	SD	Mean	SD
Set 1							
.62	0	4.06	13.45	24.92	25.69	2.18	4.95
1.00	52	47.26	10.54	33.85	27.97	37.37	25.80
1.46	65	53.90	14.75	50.92	23.05	31.95	24.84
Set 2							
1.25	0	3.52	9.94	8.12	12.61	1.62	4.39
2.03	52	35.07	9.26	23.02	16.49	16.25	13.42
2.94	65	45.52	11.61	31.68	14.00	11.37	13.45

Figure 2. Perceived shape and perceived orientation as a function of viewing condition plotted individually for each of the six subjects.

For Set 1, most subjects presented a pattern of data unlike the composite; for Set 2, all six subjects conformed to the composite picture.

Analysis of variance on the transformed orientation data showed significant main effects of Set, $F(1,5) = 7.16$, $p < .05$, Exposure Condition, $F(2,10) = 8.38$, $p < .01$, and Orientation within Set, $F(4,20) = 50.23$, $p < .001$. There was only one significant interaction: Exposure Condition by Orientation within Set, $F(8,40) = 9.76$, $p < .001$. The nature of the interaction is obvious in the right-hand panels of Figure 1. The effect of the exposure conditions increases as the standard is displaced increasingly from the frontal plane.

Shape-Slant Relations

The shape slant invariance hypothesis proposes that projective shape, perceived shape, and perceived orientation are so related that, for a constant projective shape, variations in perceived shape should be accompanied by proportional variations in perceived orientation. The results of the present experiment were in fairly good agreement with the invariance hypothesis. Under the binocular no-mask condition which yielded shape judgments that differentiated among the objectively different shapes, the orientation judgments similarly distinguished among the objective orientations. The monocular and binocular mask conditions which led to failure to discriminate among the objectively different shapes should have led to failure to discriminate orientation. Inasmuch as the failure of shape discrimination was manifested in projective shape matching, the invariance hypothesis requires pronounced underestimation of orientation. This relation was also obtained. Admittedly, these shape-slant relations are more obvious in the group data shown in Figure 1 than in the individual data displayed in Figure 2.

DISCUSSION

The experiment yielded several principal findings: (1) The mask which was partially cotermporal with the rotated standard shifted perceived shape from near correspondence to objective shape to near correspondence with projective shape. (2) The effects of the mask and the effect of cue reduction without a mask were comparable. (3) Masking and cue reduction also affected perceived orientation, causing significant underestimation of orientation relative to the objective orientations and to the judgments obtained under the binocular no-mask condition. (4) The relationship between perceived shape and perceived slant was in general agreement with the shape-slant invariance hypothesis.

The findings clarified the questions which motivated the present study. Advancing the introduction of the mask did increase conformity to projective shape relative to the effect of a following mask. Figure 3 reproduces the shape data for the binocular no-mask condition and the three binocular mask conditions, 0-, 25-, and 50-msec ISI, from the earlier experiment by Epstein et al. (1977). Also depicted are the shape data for the binocular mask condition of the present experiment. Figure 3 shows that the present masking arrangement led to slopes which were closer to zero than the slopes of the data for the nonoverlapping masks and to shape matches which were closer to the actual projective shape of the targets. Second, our data demonstrated the functional equivalence of masking and the conventional procedures for minimizing information for depth. This equivalence reinforces our hypothesis that the mask affects perceived shape by affecting perceived orientation.

Figure 4 presents a process model of perceiving shape at a slant. Essentially, the model is an explic-

Figure 3. Comparison of the perceived shapes under the binocular mask condition in the present experiment, with the perceived shapes reported under binocular mask and binocular no-mask conditions of Epstein, Hatfield, and Muise (1977, Figure 1).

Figure 4. Process model of perception of shape at a slant.

tion of the shape-slant invariance hypothesis (Epstein, 1973, 1977, chap. 1; Epstein & Park, 1963). Figure 4 will be useful in a consideration of the locus of our obtained masking effects. Sensory (retinal) registration of shape and the optical correlates of orientation, e.g., texture gradients and binocular disparity, is the first step in the sequence intervening between presentation of the distal rotated shape and the discriminative response required by the experimental task.³ The next stage is encoding a representation of projective shape and transforming the optical correlates of orientation into a code representing the orientation of the distal object. The results of these encoding stages are transmitted to the shape-slant algorithm processor. The algorithm is applied to generate a perceived shape-at-a-slant. Then, depending on the requirements of the experimental task, the subject will apply operations to the output of the algorithm in order to select a response.

A mask could have an effect at any point in the processing sequence. The mask could affect performance by disrupting contour formation and reliable registration of projective shape. However, the projective shape matches that were observed indicate that projective shape was reliably registered and encoded. Consequently, the effect must be located at another point in the sequence.

The masking effect could occur at the stage of orientation encoding or orientation utilization. By orientation encoding, we mean the process of encoding the potential information for orientation carried by optical stimulation into information about distal orientation. The large effect associated with restric-

tion to monocular viewing suggests that binocular disparity was the vital optical carrier of depth information in our experimental setting. [Monocular occlusion alters neither the oculomotor inputs nor the field (pictorial) cues. In addition, the brevity of exposure makes motion parallax associated with head movements a negligible factor and precludes convergence shifts between the near and far edges of the rotated shape. Thus, binocular disparity is implicated by exclusion.] The depth response to disparity takes time to develop (Julesz, 1971, pp. 201-217; Frisby & Clatworthy, 1975; Ramachandran & Braddick, 1973; Seagram, 1967), with estimates ranging from 50 msec to several seconds for a variety of stimulus conditions and response measures. The mask in our studies may have preempted the visual system before the processing of stereopsis had run its course. Preemption of stereopsis would leave intact the projective shape information that is available to each eye. This case would then be analogous to monocular viewing, in which projective shape information is present in the absence of encoded orientation information.

Disruption of stereopsis would be expected to lead to nonsystematic variability in judging slant. However, our results exhibited a systematic tendency toward the frontoparallel plane. This tendency suggests to us that once processing of stereopsis was arrested, the perceived orientation of the target was determined by the perceived orientation of the mask. Since the mask was perceived binocularly for 400 msec, it is likely to have been perceived as frontoparallel (veridically) so that the orientation of the target would also tend toward the frontoparallel. As processing of disparity was allowed to proceed for a longer time, i.e., as SOA increased, the influence of mask orientation diminished and perceived orientation tended toward the disparity-equivalent orientation, i.e., toward objective orientation.⁴

Although there is no direct evidence of orientation assimilation in our experiment, induction effects involving perceived orientation and depth have been reported in other experiments. Epstein, Bontrager, and Park (1962) found that the perceived slant-in-depth of a shape, which is viewed under conditions impoverished with respect to depth information is determined by the perceived slant-in-depth of the background when depth information is available for the background.

The assimilation of the slant of a test figure to the slant of the background has been discussed in terms of the equidistance tendency (Gogel, 1965, 1969). If assimilation occurred in the present experiment, it may be seen as a particular instance of this more general effect. In this case, the locus of the effect in terms of the algorithm would be on orientation encoding and processing would proceed as described above. While it is generally accepted that assigning a particular effect to a more general category of effects may confer an

advantage, the advantage is limited in the present case by the fact that a convincing explanation of the equidistance tendency has yet to be worked out.

The masking function for orientation, i.e., underestimation of orientation increasing as the time of introduction of the mask was advanced, and the relationship between the shape and orientation judgments argue strongly for locating a significant component of the masking effect in the stage of orientation encoding. However, an effect on subsequent stages cannot be definitively excluded. It is possible that the mask affects utilization of orientation information. The effect of the mask on perceived shape may be due to interruption of processing following encoding of orientation but before the orientation information is transferred to the algorithm processor. Finally, the application of the algorithm, the stage in which perceived orientation and registered projective shape are combined to generate a perceived shape-at-a-slant may be preempted by processing of the mask so that the reported shape is determined exclusively by the registered projective shape. Our data do not provide a basis for assessing these latter two possibilities.

NOTES

1. The shapes within each set were equivalent when projected orthogonally onto the frontoparallel plane. The projection of the shapes onto the retina was subject to perspective distortions (for rotated stimuli) and binocular disparity, so that the retinal projections of the shapes within each set were not precisely equivalent.

2. A Brunswik ratio is computed according to the formula $(a - p)/(o - p)$, where a is judged or perceived shape, p is projective shape, and o is objective shape (shape is defined in terms of horizontal:vertical ratio).

3. There are circumstances under which this model is not applicable. The most obvious is the case of shape-at-a-slant in random dot stereograms. In this case, perceived shape and perceived orientation are concurrent correlates of disparity.

4. Although we have inferred that restriction to monocular viewing and masking without monocular restriction both have their effect on perceived shape by inducing errors in perceived orientation in the direction of the frontal plane, it is not necessary to hold that the underestimation of orientation resulting from the two treatments is attributable to the same process. We proposed slant assimilation to account for the masking effect. The tendency toward the frontal plane under monocular viewing may have been due to other factors, which remain to be identified.

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