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INTERACTIONS BETWEEN TWO SIMPLE VISUAL PATTERNS

Wanda BUDOHOSKA and Marek CELIŃSKI

Department of Neurophysiology, Nencki Institute of Experimental Biology
Warsaw, Poland

Abstract. The interaction of linear and dot elements of simple visual patterns was examined. The following patterns were used: short line-dot, long line-dot, right turned angle-dot, downward angle-dot, circle-dot, and two dots. Except for circle-dot and two dots, perception of either of both elements of the composite stimulus deteriorates as compared to perception of the same elements when presented separately. Perception of either element is improved in the case of the circle-dot stimulus, while in the case of two dots the number of errors remained at approximately the same level. It is hypothesized that both susceptibility to influence from the other element in a composite stimulus and intensity of masking effect produced by the given stimulus depend on distance between the information points of masking and masked stimuli. The extent of susceptibility is also connected with perceptual difficulty in identification of a stimulus when presented separately.

INTRODUCTION

Numerous authors working with either psychophysiological or electrophysiological methods have found the presentation of two or more simple visual stimuli, either simultaneously or in rapid succession, to exercise an adverse effect upon the perception of at least one of these stimuli (3, 13, 14). Among the few exceptions to this rule is the recent finding from our laboratory of a facilitating interaction of two letters (2).

Negative interaction between visual stimuli is frequently accounted for by lateral inhibition occurring at the lower levels of the nervous system, i.e., in the retina or in the lateral geniculate body (5, 6, 15, 17). On the basis of Konorski's theory (9, 10), supported by some recent electrophysiological data (1, 12), and integrative activity can be presumed to occur also at higher levels of the nervous system among neurons in the gnostic areas which respond to specific visual patterns.

In most of the studies in which reciprocal inhibition between elements of a pattern has been revealed the investigators employed simple stimuli such as light dots or displays of varying size and luminescence. Reciprocal effects of various visual patterns have been studied much less, however.

The purpose of the present study was to examine the interaction between two simple visual patterns each of which is presumably represented by a separate gnostic units in the visual system. In particular the following questions were posed: What differences, if any, can be established in the type and degree of interaction between differing visual patterns presented in identical experimental conditions? What factors influence these interactions?

METHOD

The subjects were 10 adults (aged 18 to 24), in the majority students, with normal vision.

The stimuli comprised five linear patterns and one dot (Fig. 1). The angular size of the linear elements was as follows: lines 6′ in thickness

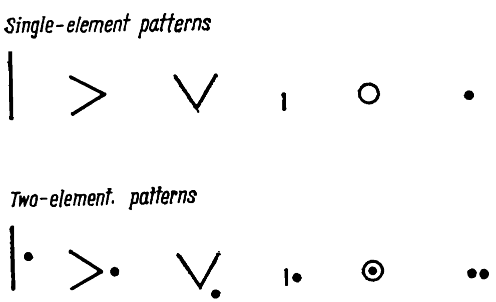

Fig. 1. Single- and two-element patterns used in the experiments.

and either 42′ or 2°3′, in length; arms of angle measured 1°32′ in length, and maximum distance between end points was also 1°32′ the dot 15′ in diameter. A linear stimulus was presented either separately or with the dot. One of the two-element stimuli consisted of two dots. The distance between the linear element and the dot, or between the two dots, was varied in the following way: 6, 10, 16, 23, 34, 46 and 72′ (measured by distances between edges of elements). In the case of the angle pointing downward the dot was placed sideways from the apex by 38″.

Every subject was tested individually in a sound-proof chamber adapted to visual research. The subject seated 1.8 m from the wall covered with a plain cloth which served as a screen. The subject was asked to identify the patterns exposed on a particular place on the screen. Single and double patterns were presented successively in random order. The subjects took part in three experimental sessions on three seccessive days. Before the first session the subject was introduced to the procedure, shown all the patterns employed in the experiment and tested for his optimal exposure durations.

In all trials exposition time was 1/60 sec, since under these conditions subjects made 60% of correct responses (in contrast to an expected 10% of correct responses based on guesswork alone).

During the experiment proper each pattern was presented 45 times at the first session, 51 times at the second session, and 52 times at the third. Throughout the experiment each double stimulus was exposed 148 times; each basic pattern was presented altogether 1036 times including all seven distance variations between elements and each single pattern had the same number of expositions. Subjects were not informed whether their identifications were correct or not.

Each stimulus presentation was preceded by a rectangular illuminated patch (sized 22°37′ × 15°23′) with a fixation dot (6′ in diameter) in the center. The fixation dot dissappeared after 1.5 sec, and the patch after a further 0.5 sec. The disappearance of this adaptation field was synchronized with the presentation, in the same position, of an illuminated patch (of exactly the same size as the adaptation field) with the stimulus in the center of fixation. Thus the stimulus appeared 2 sec after the onset of the adaptation field. The interval separating the end of one cycle and the beginning of the next was 5 sec. An interval of a few minutes was further allowed after 42 presentations, during which the subject listened to music. The average illumination inside the chamber during the intervals between stimulus presentations (measured at the subject's eye level) amounted to 71.6 lux. The adaptation display was illuminated on the average with 83.5 lux, and the fixation point with 98 lux. The illumination of the dot stimulus was 46 lux and of the two-element stimulus approx. 80 lux, but in all situations contrast between background and pattern was constant.

RESULTS

Analysis of the data was based on errors made by subjects in the identification of the presented patterns. Different types of errors were revealed with respect to identification of stimuli when they were presented individually (Table I) and in pairs (Table II). The following categories of errors were isolated for single-stimulus presentations (Table I):

TABLE I

Percentage of erroneous responses to single-element stimuli

Stimulus \ Category of error	Stimulus identified: As another single pattern	Stimulus identified: As another with a dot added	Stimulus declared as unidentified	Σ
>	4.6	1.0	3.3	8.6
|	10.9	2.6	15.1	28.6
|	2.3	0.9	6.6	9.8
V	0.6	0.2	2.8	3.6
O	4.1	1.1	6.9	12.1
•	13.4	—	36.0	49.4

1. Confusing a presented pattern with another (column 1).
2. Confusing a presented pattern and the addition of a dot (column 2).
3. Failure to identify the pattern: "don't know" response (column 3).

The following error categories were isolated for the double-element presentations (Table II):

TABLE II

Percentage of erroneous response to two-element stimuli

Stimulus \ Category of error	Errors pertaining to one element only: Dot	Errors pertaining to one element only: Line	Errors pertaining to two elements: Errors on one and dot omission	Errors pertaining to two elements: Stimulus declared as unidentified	Σ
> ·	61.0	2.4	5.8	6.8	76.0
| ·	26.4	10.5	14.2	22.1	73.8
| ·	48.4	3.7	3.6	6.6	62.3
V ·	54.9	0.7	1.2	2.0	58.8
⊙	26.8	1.3	1.9	5.3	35.3
· ·	20.8	9.5[a]	14.8	27.3	72.3

[a] In the case of two dots the errors consisted in the identification of one as a linear pattern.

1. Errors concerning dot elements. Wrong identifications, or omission of the dot element in the presented pattern. Correct identification of the linear one (column 1).

2. Errors concerning linear elements. Wrong identifications, or omission of the linear element in the presented stimulus. Correct identification of the dot element (column 2). In the case of the two-dots pattern

the error consisted in the mistaken identification of one of the dots as a linear pattern.

3. Errors concerning both elements: i.e., omission of dot and wrong identification of the linear element (column 3).

4. Errors concerning both elements. Failure to recognize both elements of the stimulus: "dont' know" response (column 4).

Statistical processing .of the data included an analysis of variance (a three-factor analysis for single-element stimuli and four-factor for double-element stimuli). In isolating these factors the assumption was made that each exerts an independent influence on the extent of error. The raw data of the experiment percentage of erroneous responses in relation to total number of presentations of the given stimulus, on a particular day, for one subject) were transformed according to Bliss' formula:

$$x = \text{arc } \sin \sqrt{\text{per cent}}$$

Variance analysis results for the single-element stimuli are shown in Table III. The principal finding is the fact of highly significant differences ($p < 0.001$) in the number of errors made in the identification of different patterns (the main A effect). There are also highly significant differences ($p < 0.001$) between the isolated categories of errors (the

TABLE III

Analysis of variance (single-element stimuli)

Source of variance	df (1)	MS (2)	F (3)
A (patterns)	5	2272.11	44.10***
B (categories of errors)	2	6073.39	117.88***
C (days)	2	71.25	1.38
A×B	10	962.23	18.67**
A×C	10	17.10	< 1
B×C	4	228.54	4.43**
Reconstructed error	486	51.52	—

** $p < 0.01$; *** $p < 0.001$.

main B effect). Highly significant differences were further discovered in the interdependency between main effects (AB and BC interaction significant at the 0.001 level). No significant differences were, on the other hand, in the number of errors made on the successive days of the experiment (the main C effect).

The analysis of variance for double-element stimuli (Table IV) revealed highly significant differences ($p < 0.001$) in the number of errors made in response to particular patterns (the main A effect), the number of errors in the isolated error categories (the main B effect) and the number of errors made on particular days (the main D effect). A significant difference was in the number of errors to patterns with varying distance between their elements ($p < 0.01$; the main C effect). Similarly as in the analysis of errors to single stimuli, the number of errors in the particular categories depended on type of presented stimulus (AB interaction significant at the 0.001 level). Likewise significant are the interdependency between type of pattern and distance (AC interaction at the $p < 0.01$ level) and the interdependency between category of error and distance (BC interaction at the $p < 0.01$ level).

Analysis of results showed differentiations of both the single and the double stimuli in terms of overall error in their identification and in terms of errors within particular categories.

To answer the basic question concerning perception of double-element stimuli — whether each element is perceived independently or whether perception of one affects that of the other — the data obtained in the

TABLE IV

Analysis of variance (two-element stimuli)

Source of variance	*df* (1)	*MS* (2)	*F* (3)
A (patterns)	5	4243.55	33.17***
B (categories of errors)	3	142555.29	1114.00***
C (distances)	6	464.17	3.62**
D (days)	2	1835.70	14.35***
A×B	15	10320.99	80.69***
A×C	30	358.33	2.80**
A×D	10	98.59	< 1
B×C	18	648.45	5.06**
B×D	6	202.66	1.58
C×D	12	83.87	< 1
Reconstructed error	4776	127.90	—

** $p < 0.01$; *** $p < 0.001$.

experiment were analyzed on the basis of a probability calculus in a manner similar to that done by Woodworth and Schlosberg (16) for evaluating interactions between two dots.

Having obtained the overall number of errors for single patterns (Table I, column 4), we computed the expected probability (p_e) of a correct or erroneous identification of a double-element stimulus composed of the same patterns, assuming the independent perception of each element. Index of that probability was taken to be the sum total of errors which could occur in the following situations: one pattern correctly identified, the other not (+ —); the second pattern correctly identified, the first not (— +); neither pattern of a double stimulus correctly identified (— —). The expected value (p_e) was then compared with the observed values (p_o) from Table II, column 5, the latter data indicating the overall number of errors for the particular double-element stimuli obtained in the experiment. Absence of difference between the two values could be taken as evidence of independent perception of each element in a double-element stimulus.

As seen in Fig. 2, the observed probability of an error made to all stimuli, except for two dots and circle–dot, is much higher ($p < 0.01$)[1]. In the case of circle plus dot it is much lower ($p < 0.01$), than the expected probability, whereas the observed and expected probabilities did not differ significantly with respect to two dots. The evidence therefore is

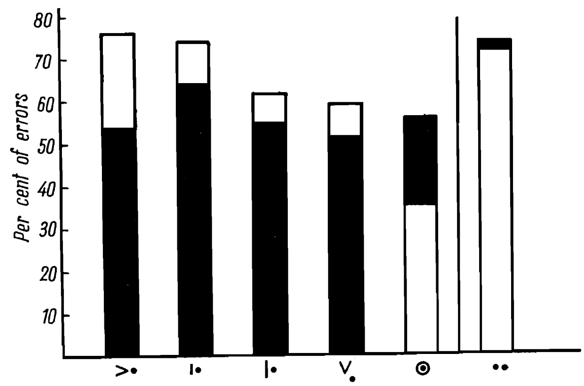

Fig. 2. Percentage of errors in perception of two-element stimuli (white part of the bars, p_o) compared with expected error probability (black part of the bars, p_e). Computation is based on the results obtained from 1036 presentations of each (single- or two-element) stimulus.

that the elements in a double-element stimulus are not perceived independently of each other but rather affect each another, except for the two dot pattern. When each angle or each linear pattern is presented together with dots this interaction has an adverse effect on perception, whereas in the case of the circle – dot it improves perception.

This raises the question whether the marked difference in the perception of double-element stimuli as compared with single stimuli is due to an increase in number of errors only for one of the elements, or of both.

In order to answer this question in relation to the dots we compared

[1] The statistical significance of the differences was evaluated for all comparisons presented using the binomial distribution formula.

the error percentages for identification of the dot when presented with a linear element (Table II, columns 1, 3, and 4 jointly) with those for the dot alone (Table I, columns 1 and 3 jointly). This comparison has shown (Fig. 3) that significantly more errors were made in response to the dot when presented in four double stimuli than when alone ($p < 0.01$), whereas errors were much fewer ($p < 0.01$) with the dot inside the circle.

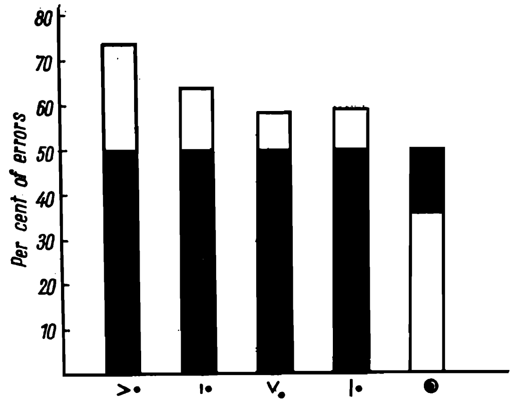

Fig. 3. Percentage of errors for dots as single-element stimuli (black part of the bars) as compared with those for dots presented in two-element stimuli (white part of the bars).

In a similar way as for dots we compared the percentage of errors made in response to the particular linear elements presented alone (Table I, columns 1, 2, and 3 jointly) with those made in response to the appropriate linear component of the double stimuli (Table II, columns 2, 3, and 4 jointly). As can be seen from Fig. 4 the percentage of errors in response to the short and long lines, and to the angle pointing right is

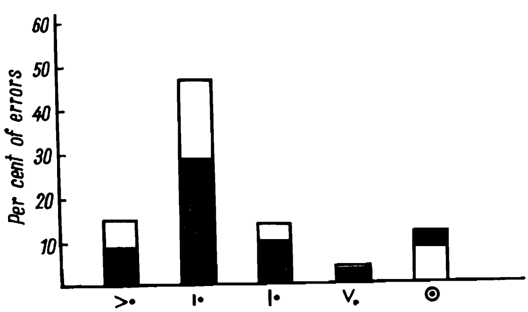

Fig. 4. Percentage of errors consisting in wrong identifications of lines in two-element stimuli (white part of the bars) as compared with those for the same elements presented separately (black part of the bars).

significantly higher for the linear element in a double-element stimulus than when presented alone ($p < 0.01$). This difference failed to reach statistical significance with respect to the angle pointing downward plus dot. Significantly fewer errors occurred in response to the circle plus dot than in response to the circle alone ($p < 0.01$).

DISCUSSION

Our results shown that as concerns single stimuli, there are marked differences among them as to the extent of error in their identification. Number of errors was greatest in response to the dot, was progressively less for identification of the short line, the circle, the long line, and the angle pointing right, and smallest for the angle pointing downward. This particular sequence in terms of perceptual difficulty suggests that the crucial thing in the identification of a pattern may be absolute size. But this cannot be the sole factor, since number of errors varied for stimuli of the same size (both angles and the long line). Reduction of errors to one half in response to the downward angle as compared to the angle pointing right may be due to familiarity of the former pattern (Roman digit five, letter V, etc.). But this does not exclude the possibility that the perceptual difficulty of a stimulus might be due to its particular shape and position in the visual field.

The results enable us to answer the central question of the present experiment, namely, whether the elements of a complex stimulus are perceived separately of whether perception of one element affects that of the other. In the case of the majority of the double-element stimuli employed in this experiment it seems legitimate to state that perception of component elements is interdependent: when two elements are presented together, the number of errors made in response to each is greater than for the same element presented as a separate stimulus. This applies to the right-turned angle–dot, short line–dot, and long line–dot. In the case of the downward angle–dot this perceptual interference occurred only with respect to the dot element; with the circle–dot, there was a distinct perceptual facilitation of each of the elements. Only the two dots did not reveal any clear-cut interaction between the two elements.

Examining possible sources of the effect exerted by the linear element on the dot, we notice that the largest error increment occurred when the dot was presented together with the right-turned angle, then when it accompanied the short line, and finally with the long line and the downward angle. Particularly striking is the fact that the long line produced fewer errors than the short line, although the latter was actually the smallest linear element to produce the greatest number of errors when presented separately. An explanation could be forthcoming if we assumed that the extent of interference depended primarily on the distance between the masked pattern (dot) and what is called the information points (4, 8) of the masking stimulus (apex of angle or end of line, in this case). Investigations carried out with an electronic model of the neuronal network (4, 7, 8) have shown that neuronal discharges of particular intensity are evoked by information points such as a break in, or end of, the line, or an edge, whereas fewer discharges are produced by those parts of the stimulus situated between the information points, owing to the inhibitory connections between adjacent groups of simultaneously excited neurons. Hence the neuronal discharges evoked by the short line can be more intensive than those evoked by the mid segment of a long line. For the same reason, the apex of a right-turned angle situated vis-á-vis the dot might have a particularly strong destructive effect upon the latter.

The same line of thinking can be applied for explanation of the results obtained with downward angle–dot and long line–dot. In both cases the reason for getting similar and at the same time the smallest masking effect could be the longer (than in the case of the other stimuli) distance of a dot from the information point of these linear patterns; as it was, the shortest distance between dot and apex of the angle was around 39′ and that between dot and end of the long line a little over 50′. If we were to assume that the interactive effect of one element upon the other depended chiefly on distance of the masking stimulus from the information points, then the absolute size of the masking stimulus could be of minor importance, and might even reduce that interaction in cases where the size of the stimulus makes for greater distance of the masked stimulus from the information points.

Examining the factors behind the extent of influence of the dot upon the line, we took account of both the absolute values and the relative increment in error on the linear element of the double stimulus as compared with these elements presented singly. In Fig. 4, where the relevant data are shown, we find the dot to affect most adversely the short line and the right-turned angle, and less acutely the long line; no distinct influence on the downward angle has been noted. This sequence of the linear elements in terms of susceptibility to interference corresponds almost ideally to their sequence in terms of perceptual difficulty when presented singly and — most significantly — in terms of the amount of masking effect produced by the linear stimulus upon the dot. The close correspondence of sequence of stimuli in terms both of masking effect and susceptibility to interference suggests that the intensity of reciprocal interaction is determined by the same factor, which we suppose to be the distance between the information points of the two patterns. The observed effect of size of linear pattern upon susceptibility to interference from the dot might also be explained by the distance of important information points in these patterns from the interfering stimulus. For instance, the right-pointing angle, although bigger than the short line and equal in size to the long line, might be less susceptible to interference in view of the fact that its two important information points (ends of its arms) were further away from the dot than the ends of either the short or the long line.

This line of argument is superficially contradicted by two facts: perceptual facilitation of either element in the circle-dot pattern and the absence of any interaction between two dots. But these facts can be accounted for by Konorski's theory of gnostic units, according to which a familiar composite stimulus which has a unitary representation in the gnostic field does not set up interference between its component elements; on the contrary, perception of each element is facilitated because any one alone may stimulate perception of the entire gnostic field.

Thus facilitated perception of both elements of the circle-dot pattern may have been due to a unitary identification of this pattern, especially so as a dot in a circle is a common pattern as well as a symmetrical one; in an earlier study (11), symmetry has been found to reduce the inhibitory interaction between elements of a composite stimulus and hence to favor their integration.

The absence of distinct interaction between two dots could by explained also by reference to Konorski's views: a familiar stimulus is represented in the gnostic field not by a single gnostic unit but by a greater number of such units which exercise no antagonistic effects upon each other. Hence identical stimuli (in this case two dots) should not interfere with each other. At the retinal level, where neurons do not react to specific stimuli, however, there should be an interactive effect between two dots, especially when close together, irrespective of identity. This supposition is borne out by the fact that the number of errors made in the identification of two dots declines dramatically (from 90 to 65% approx.; M. Celiński, in preparation); in the distance interval of 6′–10′, this decline being highly significant ($p < 0.01$), whereas the number of errors for the distances remains at about the same level.

These data suggest that inhibition and facilitation responsible for the hampering and improving of perception of the presented patterns take place at different levels of the visual system. The influence of distance between important information points of masking and masked stimuli, and also of size of masked stimulus, upon the masking effect may be accounted for by lateral inhibition occurring at the lower levels of the visual system. Among the facts supporting a supposition that the observed interactions take place at the higher level of the visual system is the decrease in number of errors on successive days of presentation of double-element stimuli. In view of the fact that reduction in number of errors failed to reach statistical significance for identification of single-element stimuli, we would be justified in assuming that the decrement in error in response to double-element stimuli was due less to an improved perception of each element separately than to a weakened inhibitory interaction between them. A similar conclusion has been reached by Schiller (13), who noted a decrease in the masking effect between two letters on successive days. It would be equally difficult to explain the results obtained for the presentation of circle–dot and two dots by reference to peripheral processes. A much more plausible explanation would seem to be that the identification of such stimuli involves higher-level processes either within single gnostic units or between such units.

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Wanda BUDOHOSKA and Marek CELIŃSKI, Department of Neurophysiology, Nencki Institute of Experimental Biology, Pasteura 3, 02-093 Warsaw, Poland.