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CHANGES IN VISUAL SPATIAL ORGANIZATION: RESPONSE FREQUENCY EQUALIZATION VERSUS ADAPTATION LEVEL [1]

WILLIAM STEINBERG AND ROBERT SEKULER [2]

Northwestern University

Two experiments tested alternative explanations for the apparent change in visual spatial organization produced by exposure to "adapting" or anchor stimuli. The alternative positions evaluated were that the change was perceptual (adaptation-level [AL] theory) or that it was the result of response bias (response-frequency-equalization theory). In Experiment I, judgments of spatial organization were obtained for 11 different matrices of dots in a series ranging from columnar organization to rowlike organization. The *S*s were exposed on alternate trials to dot patterns of extreme horizontal (rowlike) organization, to extreme vertical (columnar) organization, or to neither (control group). As predicted by both theories, judgments were systematically affected by the adapting stimuli. In Experiment II, the influence of response bias was nullified by a forced-choice procedure. Contrary to AL theory, once response bias was eliminated group differences vanished.

Adaptation is a change in sensory response which follows the presentation of some stimulus. The study of visual adaptation provides a powerful analytic tool for identifying the nature and character of sensory mechanisms which support various perceptual experiences (Weisstein, 1969). Adaptation-level (AL) theory provides one general framework which integrates, in a limited set of equations, many apparently unrelated phenomena connected with adaptation (Helson, 1964).

While adaptation may potentially follow exposure to any stimulus which differs from the current base-line level or pattern of stimulation (Andrews, 1964; Held, 1962), it is important to distinguish actual changes in sensory response from ersatz forms of adaptation. Only the former changes are likely to illuminate sensory processes. Sekuler and Erlebacher (1971) identified one possible artifact which could produce ersatz adaptation, the tendency of *S*s to use available responses with equal frequency. Among the experiments singled out as demonstrations of ersatz, rather than genuine, adaptation are several reported by Bell and Bevan (1968). In Bell and Bevan's first experiment, which may be considered as the prototype for all their experiments, *S*s judged the spatial organization of a series of dots arranged on the vertices of an imaginary matrix. When the vertical distances between dots are greater than the horizontal distances, the dots seem to be organized in rows. When the vertical distances between dots are less than the horizontal distances, the dots seem to be organized in columns. These observations demonstrate the operation of the gestalt principle of "proximity." Bell and Bevan used a graded series of dot matrices ranging from extreme rowlike organization through neutral organization (vertical distances equal to horizontal distances) to extreme columnlike organization. Each stimulus was judged, using the method of single stimuli, as rowlike or columnlike. The point of subjective equality (PSE) can be defined as the stimulus which appeared most nearly neutral (i.e., judged rowlike with $P = .5$). The PSE was determined for each of three groups. For the column group, every other stimulus to be judged was extremely columnar in its organization—such a stimulus was virtually certain to elicit a column judgment. For the row group, every other stimulus was extremely rowlike in its organization—being virtually certain to elicit row responses. A final

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[2] Requests for reprints should be sent to Robert Sekuler, Cresap Laboratory of Neuroscience and Behavior, Northwestern University, Evanston, Illinois 60201.

group, the control group, was tested without the introduction of extreme anchor stimuli. The PSE of the column group was shifted away from the neutral stimulus of the series toward columnlike stimuli; the PSE of the row group was shifted in the opposite direction, toward rowlike stimuli. Bell and Bevan attributed the opposite shifts in PSE to sensory adaptation produced by repeated presentation of the extreme anchor stimuli. This finding, they claimed, was consistent with Helson's (1966) belief "that there are spatial adaptations, no less than chromatic adaptations, which are responsible for the way spatial patterns are formed [p. 173]." This claim has since been repeated by Avant and Bevan (1971) in their discussion of the Bell and Bevan experiments.

Sekuler and Erlebacher (1971) proposed that the data of Bell and Bevan had nothing whatever to do with sensory adaptation, but merely resulted from response bias, the tendency for *S*s to use all available responses with approximately equal frequency. Response-frequency-equalization (RFE) theory argues that *S*s in Bell and Bevan's row group, having made a row response to every other (anchor) stimulus, would, whenever uncertain as to the correct response, make column responses. This would shift the PSE away from the neutral stimulus toward rowlike stimuli. The same argument could be applied to the column group, producing the obtained shift in the PSE toward columnlike stimuli. A more formal statement of this theoretical position can be found in Erlebacher and Sekuler (1971).

The present paper reports two experiments designed to discriminate between ersatz and genuine sensory adaptation. The first experiment is a replication of the original Bell and Bevan (1968) study, done to ensure the comparability of our stimuli and procedures to theirs. In the first experiment, like Bell and Bevan, we used the method of single stimuli. The second experiment, with the same stimuli as the first, uses a method drawn from the realm of objective psychophysics, the forced-choice method (Green & Swets, 1966). In the past this method has been useful for discriminating sensory effects from effects attributable to decision processes. In the present context, forced-choice procedures show that Bell and Bevan mistook the effects of response-frequency equalization for real sensory adaptation.

Experiment I

Method

Subjects. Thirty undergraduate students enrolled in an introductory psychology course at Northwestern University served as *S*s. Ten *S*s were randomly assigned to each of three groups; all *S*s in any group were run simultaneously.

Materials and procedure. The stimuli were eleven patterns of black, .5-in.-diam. dots. Each pattern contained 36 dots within an 8-in. square. Slides were projected onto a white beaded screen by means of a projector equipped with a tachistoscopic shutter. A black velvet mask covered most of the screen, leaving an irregular-shaped opening through which the slides were projected. On one side of the opening was a large photograph of the row anchor pattern labeled "rows"; on the other side was a similar photograph of the column anchor pattern, labeled "columns." The pattern on the photographs was also 8 in. square. The ratios of the horizontal to the vertical spacings of the dots for the 11 stimuli and the two anchors were identical to those used by Bell and Bevan (1968). These ratios in the columnar patterns were 1.11, 1.25, 1.44, 1.67, and 2.00, and in the row patterns were .90, .80, .70, .60, and .50. The neutral stimulus, of course, had a horizontal to vertical separation ratio of 1.00. Ratios for the column and row anchors were, respectively, 10.0 and .10.

The *S*s were seated along three concentric arcs centered on the screen. The average viewing distance was 15 ft., causing the stimuli to subtend, for the average *S*, approximately 2° 30′ of visual angle. The experiment was conducted in a partially darkened room. Light areas of the stimuli had a luminance of 60 cd/m^2 and had a contrast of approximately .80. Each slide was presented for 500 msec., followed by a 4.5-sec. interval during which *S*s could mark either "R" or "C" on their data sheets, indicating a judgment of row or column organization.

The three groups of *S*s were treated as Bell and Bevan (1968) treated their groups. The *S*s in all three groups received 55 experimental trials each, in five independent block randomizations of the 11 test stimuli. In addition, on every other trial the column group was given an extreme columnlike stimulus (described previously). The row anchor group received an extreme rowlike stimulus on the corresponding trials. The control group received no anchor stimuli, giving judgments on just the 55 experimental trials.

Results and Discussion

The proportion of row judgments for each *S* and stimulus was computed.[3] For purposes of data analysis, these proportions were transformed to twice the arc sine of the proportion's square root. When the proportion itself was either 1.0 or 0.0, the transformation was performed on values of .9 or .1, respectively. These substituted proportions are $\pm 1.0/2n$, where n is the number of observations upon which the proportion is based. Only data from 55 experimental trials have been analyzed since they are the only ones common to all groups. It might be mentioned, however, that row responses were made to virtually 100% of the interpolated anchor stimuli given the row group, and column responses were made to virtually all of the interpolated anchors given the column group.

The analysis of variance showed that the differences among groups, $F(2, 27) = 9.01$, and the main effect of stimulus type, $F(10, 270) = 80.07$, were both highly significant ($p < .01$). The interaction between stimulus type and group proved nonsignificant, $F(20, 270) = 1.56$, $.06 < p < .07$. As in the Bell and Bevan (1968) experiment, which the present study attempts to replicate, the proportion of row judgments is greatest for the column group, least for the row group, and intermediate for the control group.

Least squares fits to the z-transformed proportions were obtained in order to estimate the points of subjective equality (PSE) for each group. The equations of the best-fitting lines were: $z = -1.82s + 1.93$, $z = -1.43s + 1.15$, and $z = -1.90s + 2.21$, for the control, row, and column groups, respectively, where z is the unit normal deviate of the proportion of row responses, and s is the ratio between horizontal and vertical distances in a stimulus pattern. The root mean square errors about the fitted lines are .35, .35, and .34, respectively. Solving the least squares for $z = 0.0$ gives PSEs of 1.06, .80, and 1.16 for control, row, and column groups. Bell and Bevan (1968) report 1.06, .87, and 1.19 as the corresponding PSE values. The correspondence between the values in our experiment and those of Bell and Bevan is striking.[4] Just as in the Bell and Bevan study, then, the PSE for the column group is shifted toward columnar stimuli, while the PSE of the row group is shifted in the opposite direction.

To facilitate visual comparison between our data and those of Bell and Bevan (1968), Figure 1 shows our data plotted as Bell and Bevan gave theirs.

[3] For the row group, one presentation of the most extreme row pattern (other than the row anchor pattern) was lost because of mechanical failure. Thus, this pattern was only presented four times to the row group. A similar error caused the column group to receive only four presentations of the neutral pattern. These losses have been compensated by using percentages as the basic data for the experiment rather than frequencies.

[4] Although the numerical near identity of our data and those of Bell and Bevan (1968) is encouraging, too much ought not be made of that identity, since one cannot tell from their article how psychometric functions were fitted and PSEs estimated. William Bevan was kind enough to send us the data from the experiment by Bell and Bevan and has informed us that they fit their psychometric functions "with the aid of French curves." To insure comparability between our PSE estimates and the estimates for the Bell and Bevan experiment, we have obtained least squares fits to their data using the same procedure as for our own data. The PSEs which result from the least squares equations are 1.13, .82, and 1.23, for the control, row, and column groups in the Bell and Bevan experiment.

An examination of the residuals (predicted z values minus obtained z values) from our least squares fits indicates that there is a distinct nonlinear component in our data which remains after the z transformation (see Draper & Smith, 1966). This means of course that the original, untransformed data were not terribly well described by the integral of the normal curve. We believe that at least a large portion of this nonlinearity in z for the z-transformed data can be accounted for by substantial numbers of stimuli, at either end of the continuum, that lie essentially at the basement and ceiling of the psychometric function. This supposition is supported by the outcome of fitting linear functions to the z-transformed proportions of only the middle five stimuli, i.e., from 1.25 to .80, horizontal to vertical ratios. The best-fitting equations for these truncated least squares fits are: $z = -3.82s + 3.80$, $z = -2.32s + 1.81$, and $z = -3.57s + 3.83$, for control, row, and column groups, respectively, with average root mean square errors of .14. The PSEs derived from these truncated psychometric functions are .99, .78, and 1.07, preserving quite nicely the magnitude and order of differences among the three groups while shifting all the PSEs somewhat toward lower horizontal to vertical ratios.

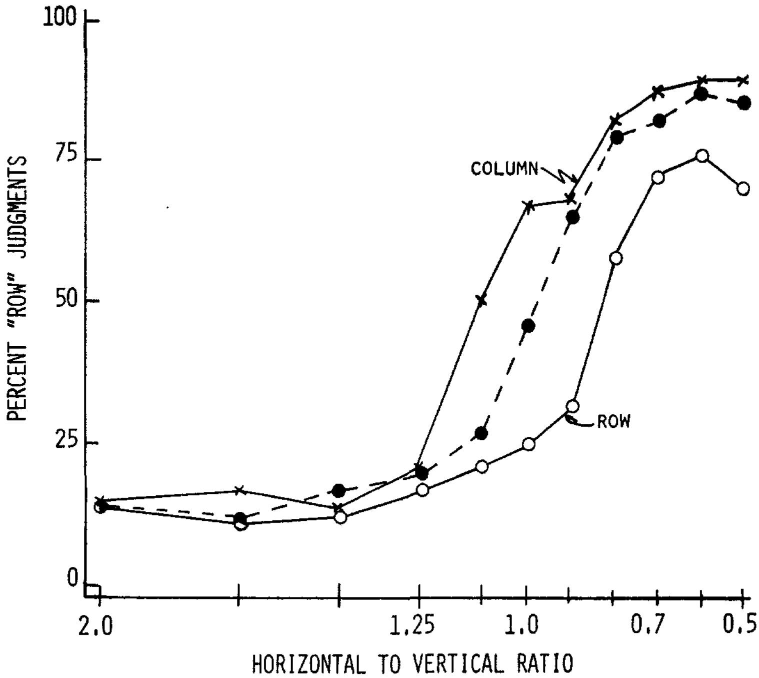

FIG. 1. The percentage of row responses for each group as a function of the ratio of horizontal to vertical separation of dots in the stimuli. (Crosses show data for the column group, filled circles for the control group, and unfilled circles for the row group.)

EXPERIMENT II

The first experiment established the comparability of our stimuli and apparatus to those used by Bell and Bevan (1968). It will be recalled that both RFE theory and AL theory made the same predictions for that experiment. The second experiment uses the same stimuli and apparatus in a situation where adaptation-level theory and response-frequency-equalization theory make quite different predictions. On each trial, two dot patterns are presented and *S* makes a forced-choice response, indicating which of the two patterns is the more nearly neutral (i.e., least like either rows or columns in its organization). For all three groups in this experiment, the comparisons of interest are between a physically neutral dot pattern and one of the eleven patterns used in the first experiment, including the neutral pattern itself. For one group, row group, on every other trial *S*s are given two identical, extreme row anchor patterns, again being asked to judge which of the two is more neutral. The repeated presentation of extreme row stimuli should, according to adaptation-level theory, shift the adaptation level toward rowlike stimuli. This would cause physically neutral stimuli, as a result, to appear slightly columnar. The experimental consequences of this shift in AL may be represented as follows: When a slightly rowlike pattern and a neutral pattern are presented on the same trial, the slightly rowlike pattern, being closer to the AL, should be judged—erroneously—as the more neutral of the two. In general, AL theory predicts a shift in the PSE for the row group away from the physically neutral stimulus toward a more rowlike pattern. For another group in Experiment II, the column group, *S*s see, on alternate trials, two identical extreme columnar patterns. Again, the repeated presentation of extreme column stimuli should, if AL theory is correct, shift the AL toward columnar stimuli, causing a physically neutral pattern to appear rowlike. By reasoning similar to that given above for the case of the row group, for the column group, adaptation-level theory predicts a shift in the PSE away from a physically neutral pattern toward one that is columnar. In Experiment II, a third, control, group receives no extreme anchor or adapting stimuli. For all groups, on the trials when a neutral stimulus is compared against one of the eleven test patterns, the temporal position, first or second, of that neutral stimulus was randomized. According to response-frequency-equalization theory, this randomization should spread the effects of any possible response bias (i.e., bias produced by using too many first or second judgments) evenly across all neutral and nonneutral stimuli alike. With response bias thus cancelled out, if there are differences among the groups—similar to those of the first experiment—we may conclude that the data of the first experiment and those of Bell and Bevan (1968) were the product of genuine sensory adaptation. However, with response bias cancelled out, should the differences among the groups disappear, we must conclude that the differences in the first experiment and those by Bell and Bevan were the result of ersatz adaptation, of the tendency of *S*s to use available responses with equal frequency.

Method

Subjects. Thirty-three undergraduate students from lower-level psychology courses served as *S*s. They were paid $2 for their service and, in addition, were informed about their eligibility for a $5 bonus that would be given to the single *S* whose judgments of neutrality had the fewest errors. The instructions about the bonus, which was actually paid, served to enhance attention and concern for accuracy in judgment. Eleven *S*s were assigned randomly to each group.

Materials and procedure. With the following exceptions, the materials and procedure were the same as those described for Experiment I. The *S*s in all groups were given the following sequence of events on each trial: One slide was presented for .5 sec.; then, after an interval of 2 sec., another slide was presented for .5 sec. The *S*s had the following 9 sec. to mark either "1" or "2" on their data sheets to indicate whether they thought the first or second pattern presented was the more neutral. The *S*s in the control group received 55 trials, representing 5 independent block randomizations of the 11 test stimuli, each being paired with the neutral stimulus. The *S*s in the row group received the same order of these 55 trials and, in addition, on every other trial were presented with two extreme row patterns, identical to the row anchors used in Experiment I. The *S*s in the column group were treated as those in the row group except that they were shown pairs of extreme column stimuli on alternate trials rather than extreme row stimuli. On those trials, for all groups, where a neutral stimulus was being compared to one of the 11 test stimuli, the temporal order of the neutral stimulus, first or second presented on that trial, was randomized. The *S*s were run one group at a time with a seating arrangement similar to that of Experiment I.

Results

Only the data from the 55 trials per *S* that all groups had in common were analyzed. Judgments of the extreme anchor stimuli were not analyzed since they were included only to produce a possible differential shift in AL. The basic data were the number of times each of the 11 test stimuli was judged less neutral than the physically neutral stimulus. The frequencies were converted to proportions and then transformed to twice the arc sine of the proportion's square root. These transformed scores were entered into an analysis of variance. As in Experiment I, proportions near 1.0 or 0.0 were adjusted to .9 or .1. The analysis of variance showed only a significant main effect of stimulus type, F (10, 300) = 41.85, $p < .01$, with neither the main effect of group nor the interaction between groups and stimulus type approaching statistical significance, F (2, 30) = .96, $p > .50$ and F (20, 300) = 1.11, $p > .30$. The data, expressed as percentages, are shown in Figure 2. The same curve has been drawn through the data for all groups. This curve represents the mean values for all three groups. The figure is presented this way to permit the reader to determine for himself, independently of the analysis, whether there are systematic differences among the groups. This visual presentation plus the analysis of variance leads us to conclude that the large and powerful group difference found in Experiment I and in the Bell and Bevan (1968) experiment has evaporated under the forced-choice procedure used in the present experiment.

General Discussion

The article by Bell and Bevan (1968) reported four different experiments. Each experiment demonstrated the effects of extreme

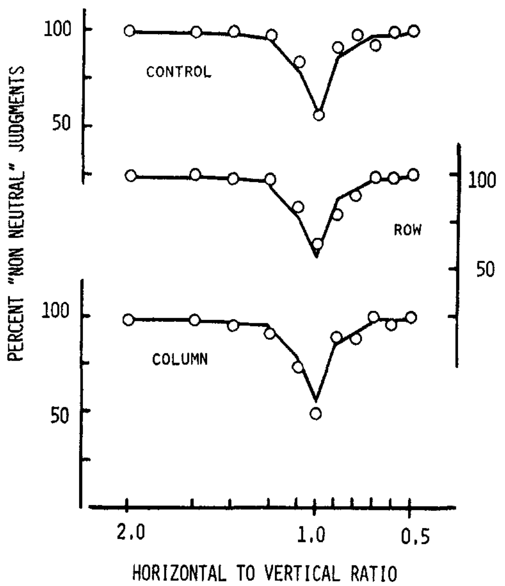

FIG. 2. Proportion of nonneutral responses as a function of the ratio of horizontal to vertical separation of dots in the stimuli. (Data for the control group are shown in the top section, data for the row group in the middle section, and for the column group in the bottom section of the figure. Each set of data has been displaced by a constant amount [.75] above its lower neighbor to facilitate inspection. The curve shown in every panel is the grand mean.)

anchor stimuli upon a different gestalt principle of perceptual organization. The experiment that we have replicated was one which was designed to show that the contribution of "proximity" could be altered by adaptation level. Other experiments purported to show similar effects for the gestalt principles of "similarity," "good continuation," and "closure." The present study shows that the effects reported by Bell and Bevan (1968) and alleged to show changes in the perceptual operation of proximity are merely the product of response bias, as suggested some time ago by Sekuler and Erlebacher (1971). This leads us to propose that most, if not all, of the experiments reported by Bell and Bevan are similarly explicable in terms of response-frequency equalization. Thus, rather than supporting Helson's (1966) proposition that there exist forms of spatial adaptation analogous to chromatic adaptation, we believe Bell and Bevan's data support the claim that a wide variety of psychophysical experiments may be "contaminated by the artifactual effects of *S*'s tendency to use response with approximately equal frequency [Sekuler & Erlebacher, 1971, p. 311]."

It must be made clear that we are not taking the position that all evidence of spatial adaptation is to be written off as being the result of response bias. We believe that there are several valid demonstrations of spatial adaptation, some measured under forced-choice conditions. These experiments make rival hypotheses extremely difficult to conjure up. We also believe that wherever possible, forced-choice procedures ought to be used in studies of visual adaptation or, at an absolute minimum, precautions should be taken to remove response-frequency equalization as a rival hypothesis for explaining findings that presumably are meant to illuminate working of sensory processes. This caveat must be seriously considered regardless of the psychophysical procedure used—whether it be method of constant stimuli, limits, or adjustment. The present experiments do show that, given converging operations, it is possible to distinguish sensory effects from those which are due to response processes or biases.

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