SPECIFIC AND GENERAL CONTOUR ADAPTATION EFFECTS FOUND USING A SELECTIVE ADAPTATION PARADIGM

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Summary.—There is evidence for discrete property analyzers in mammalian visual systems. Research has indicated that prolonged stimulation of such units reduces their sensitivity to subsequent stimulation. Psychophysical studies have employed this effect, termed selective adaptation, to study feature extractors in the human visual system. The purpose of this study was to determine the role of density and deviation in the adaptation figure on the recognition thresholds of simple and complex test figures. A selective adaptation paradigm was employed. A strict property analyzer model suggests that increases in density, deviation, or complexity should lead to an increased recognition time for the test figures. This was not confirmed. The complexity of the test figure had no effect on its recognition time. Both increased density and deviation did have an effect on the recognition times of the test figures. The results thus suggest that contour adaptation involves at least two processes: a general, probably peripheral effect due to the fatigue of visual receptor units and a more specific effect generated by the similarity between test figure and adaptation contours, independent of the site of stimulation.

Psychophysical and electrophysiological data have suggested the existence of property analyzers in the mammalian visual system. This evidence suggests the existence of cells which are selectively tuned to detect particular stimulus characteristics (Hubel & Wiesel, 1961, 1962, 1963, 1965). Specific attributes such as movement, color, contour, and size selectively stimulate specific cells in the visual system (Andrews, 1965; Barlow, et al., 1964; Houlihan, et al., 1968; Kozak, et al., 1965; McCollough, 1965; Sekuler, et al., 1968).

Hubel and Wiesel (1965) demonstrated that prolonged stimulation of these cortical cells reduces their sensitivity. This process is based on the observable physiological event that one result of prolonged stimulation on neural firing is that this stimulation reduces the frequency of firing. Following this, the neural system needs time to recover. Stimulation during the refractory phase requires a stimulus of greater magnitude than the original stimulus. Evidence for this effect in the visual system was provided by Barlow and Hill (1963). They reported that prolonged stimulation of directionally sensitive retinal ganglia cells in the rabbit resulted in gradual response inhibition, followed by a refractory phase.

The psychophysical analog of this fatigue-like effect is termed "selective adaptation" (Weisstein, 1970). That is, prolonged viewing of stimulus features tends to depress the detection threshold of their specific property analyz-
ers. The adaptation effect then is a result of 'fatigue' on the part of those detectors which are stimulated by those specific features. The magnitude of the adaptation effect can be estimated by the amount of time in milliseconds which a subject requires to recognize correctly a test figure immediately after an adaptation period.

In studies concerned with the relationship between motion and its respective property analyzers, Sekuler and Ganz (1963) used retinally stabilized gratings as stimuli and found higher thresholds for test gratings moving in the same direction as adaptation gratings than for test and adaptation stimuli moving in opposite directions. By varying both the orientation and velocity for test and adaptation gratings, Sekuler, Rubin, and Cushman (1968) found an interaction such that gratings of similar direction and orientation produced the highest thresholds.

Of interest are the effects of adaptation on lines and contours. Andrews (1965) demonstrated that for specifically oriented vertical and horizontal lines, bias (constant error) increases as a function of the stimulus duration. Houlihan and Sekuler (1968) used a selective adaptation paradigm to demonstrate that the adaptation effect on the gratings decreased as the adaptation figure was rotated away from the vertical orientation of the test bar. Blakemore and Campbell (1969) found that a 30-sec. adaptation period to a grating elevated the detection threshold of a similarly oriented test figure which was presented immediately afterward. This was accompanied by the suppression of the visual evoked potential. Campbell and Kulikowski (1966) used a contrast method of adjustment to determine thresholds for gratings. Their results indicated that the more similar the test and adaptation gratings were in their orientation the greater the threshold change. There was no effect if the test and the adaptation gratings were perpendicular to each other, but as the orientations became more equal, the effect increased significantly. The strongest effect was found within 30° of the test orientation. When they attempted to determine the effect of adaptation on diagonal lines by the speed and accuracy of identification of a variably tilted test figure, Gilinski and Cohen (1972) found that both reaction time and threshold increase as a function of the extent to which adaptation and test figures were similarly oriented and the length of the adaptation period. In their study, Blakemore and Sutton (1969) noted the effect caused by prolonged viewing of an adaptation grating is the distortion of the test grating. The vertical test bands which, prior to prolonged exposure, appeared equally spaced were perceived by subjects as narrower after viewing the adaptation gratings for 1 min.

It can be concluded from the above research that the relative orientation of adaptation and test figures is critical in determining the magnitude of adaptation effects. The purpose of this study was to examine the effects of two attributes of the adaptation field on figural recognition and one attribute of the
test field on figural recognition. The first variable was the angular deviation of the adaptation figure which was defined as the angular deviation in degrees of all lines in a 20.3-cm × 20.3-cm field from a vertical position. The second variable was the density of the adaptation field which was defined as the number of black 33-mm lines drawn on a white 20.3-cm × 20.3-cm field. The third variable was the complexity of the test figure, defined as the number of turns in each test figure.

It was hypothesized that by increasing the deviation of a test figure, there would be a greater probability that the contour orientation of the adaptation figure and the test figure would be similar. Hence, an increase in recognition time would be found.

Previous research has not looked specifically at the effect of adaptation field density on subsequent recognition but, a property analyzer model would suggest that by increasing the density in the adaptation figure a larger percentage of property analyzers would be fatigued and hence there would be a larger adaptation effect. Therefore, the second hypothesis was that an increase in density in the adaptation field would lead to an increase in the recognition time for a test figure.

The third hypothesis dealt with the complexity of the test figure. According to the property analyzer model, as the total number of angles in a test figure was increased, the number of property analyzers in the retinal field which were responsible for the perception of these particular angles was also increased. The recognition time for complex test figures would be greater than that for simple test figures since a larger proportion of the property analyzers necessary for the perception of the complex test figure were likely to be fatigued after the adaptation period and must recover before accurate recognition of the complex test figures could occur. The third hypothesis was that as the complexity of the test figure was increased, the recognition time for that test figure would be increased.

**METHOD**

This study was conducted employing an adaptation paradigm. Adaptation to one of 10 figures was followed by a brief presentation of a test figure which the subject attempted to recognize. Essentially, the study was concerned with the recognition threshold of a test figure which was viewed in a portion of the visual field which had been previously stimulated for a 30-sec. period.

**Subjects**

The subjects for this experiment were four female subjects and one male subject all of whom had 20/20 corrected vision.

**Apparatus**

Two Gerbrands tachistoscopes, Models T-2B-C and T-1C-3C, provided...
three-channel capabilities for this study. Gerbrands Model 110A and 130 Tachistoscope Timers, plus a Hunter Model 111-C Timer were used to control adaptation and test figure presentation intervals. Gerbrands Model 402 and T-2B Tachistoscope switching units completed the system.

All adaptation and test figures were presented at 1.90 ft-c. luminance. Subjects' fixations on a spot in the center of each adaptation figure and subsequent test figures were perceived in the same retinal locus.

**Adaptation Figures**

The adaptation figures consisted of nine computer plots, varying in density and deviation. Density was defined as the number of black 33-mm lines drawn on a white 20.3-cm by 20.3-cm field, while deviation was defined as the angular deviation in degrees of all the lines in a 20.3-cm by 20.3-cm field from a vertical position. Three levels of density were employed in this study. The first was 500 lines (low density), the second was 1500 lines (medium density), and the third was 2500 lines (high density). Three levels of deviation were also established in this experiment. Low deviation was defined as occurring when the deviation of the lines from a vertical position was zero. Those lines whose standard deviation was 30° were considered medium deviation, while high deviation applied to those whose standard deviation was 60°. The angular deviations of 0°, 30°, and 60° were approximated by the computer as programmed. Table 1 depicts the 3 by 3 matrix formed by the adaptation figures, with the actual angular deviations of the lines. The average of angular deviations was calculated after the lines were drawn by the computer.

In the center of each adaptation figure was a red dot which served as a fixation point for the subjects. A tenth adaptation figure included in the experiment was a blank white field with a red dot in the center.

**Test Figures**

The 10 test figures for this experiment consisted of adjoining straight black lines of various lengths on a white field which were randomly drawn by a computer in order to form a nonsense figure. Each test figure was located in the center of the subject's visual field and within the perimeter of a 7.62-cm radius of the center. Two types of test figures were employed in the experiment, simple and complex. The complexity of the test figures was defined by

<table>
<thead>
<tr>
<th>Actual Angular Deviations in Degrees of Adaptation Figures</th>
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<tbody>
<tr>
<td>Density</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>High</td>
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</table>
the number of turns in each test figure. The number of turns in the five simple test figures were 5, 6, 7, 8, and 9, whereas the number of turns in the five complex figures were 20, 21, 22, 23, and 24.

Procedure

At the beginning of each test session, the experimenter randomly selected an adaptation figure for the subject to view for that particular session. The procedure for each trial was identical throughout the experiment. First, a 30-sec. adaptation period occurred during which time the subject was requested to fixate on a point at the center of the inspection figure. Immediately following the adaptation period, channel one, in which the inspection figure had been presented, was shut off and a test figure was shown for a predetermined interval on channel two. At the end of the exposure period for the test figure, channel two was turned off and a blank illuminated field then appeared on channel three, thus concluding the presentation sequence. At this point, the subject was asked to recognize the test figure which had just been presented. His response was then recorded by the experimenter. Subjects were given no indication of their performance until the entire study was completed and were thus unaware of whether their responses were correct or incorrect. In addition, the 10 test figures were presented in random order during each time interval so that the subject could not predict the order of presentation. After each trial, the test figure was removed from the tachistoscope even when two successive presentations of the same figure were necessary.

The recognition threshold for each adaptation-test figure combination was determined under monocular stimulation, using a modified form of the ascending method of limits (Engen, 1972). This method was chosen in order to minimize cumulative adaptation effects. The procedure was as follows. After each 30-sec. adaptation period, a test figure was presented for a 40-msec. inspection period. All the test figures were presented in random order during this interval, one after each adaptation period. When all 10 test figures had been presented at 40 msec., the responses were scanned for correct recognitions. When a test figure was correctly recognized, that figure and any other test figures which were correctly recognized were again presented following an adaptation period. The time setting for these trials was 2 msec. lower than the original inspection interval, that is 38 msec. If the test figure was properly recognized, the inspection interval was steadily decreased in 2-msec. increments until the subject failed to recognize the test figure. At all times, there was a minimum of two test figures presented per time interval. A narrow range of inspection intervals was constructed in which the test figure was reliably recognized. This was achieved by obtaining the three consecutive 2-msec. intervals in which the test figure was recognized correctly and which had directly preceded the inspection interval in which the subject failed to recognize the
test figure. If a subject failed to recognize the test figure at 40 msec., the same procedure as outlined above was followed with the exception that the inspection interval for the test figure was presented for increasing 2-msec. trials. The median value in a series of three successive correct recognitions within a 6-msec. span was used as the recognition value for that particular adaptation-test field combination.

This procedure was continued until recognition thresholds were determined for all test figures paired with a particular adaptation figure. Following this, the entire procedure was repeated employing another adaptation figure. One adaptation figure was used during each session, and the order of presentation of these adaptation figures was randomized. The recognition thresholds for the 10 test figures was determined for each of the 10 adaptation figures, for a total of 100 conditions.

The recognition threshold for each of the 10 test figures was determined following adaptation to a blank field for each subject. The threshold value for each test figure was then subtracted from the threshold values for that particular test figure for each of the nine adaptation figures. The resulting difference score obtained for each adaptation-test figure combination controlled for absolute threshold differences between subjects as well as for differences in recognition thresholds of individual test figures.

RESULTS

Both a between-subjects and a within-subjects analysis of the data were conducted.

Between-subjects Analysis

As stated in the Method, a difference score was computed for each of the subject's recognition times. The purpose of the difference score was to subtract out the absolute recognition time, which was the recognition time obtained when the adaptation field was a blank field. The difference scores for each subject were then analyzed by employing a pseudo-four-way analysis of variance, a minor modification of McNemar's Case XV (McNemar, 1962).

Table 2 presents the mean difference recognition times in milliseconds for each subject for simple and complex test figures by density by deviation.

A separate analysis of variance was computed for each subject in this study. This analysis was followed by a strength of association test (Hays, 1973). Table 3 summarizes the analysis of variance performed for each subject and the $\omega_1^2$ for each significant effect. It can be seen in Table 3 that three effects were significant ($p < .05$) for all five subjects. There was one subject for whom a fourth effect was significant.

The complexity effect was not significant for any subject. There was no significant difference in the recognition times for simple as compared with
<table>
<thead>
<tr>
<th>Density</th>
<th>Subject M. C.</th>
<th>Subject P. G.</th>
<th>Subject P. C.</th>
<th>Subject R. P.</th>
<th>Subject M. W.</th>
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<tbody>
<tr>
<td></td>
<td>0°  30°  60°</td>
<td>0°  30°  60°</td>
<td>0°  30°  60°</td>
<td>0°  30°  60°</td>
<td>0°  30°  60°</td>
</tr>
<tr>
<td>500</td>
<td>8.8 14 20.8</td>
<td>4.8 19.2 24.4</td>
<td>4.0 24.0 23.2</td>
<td>5.2 13.2 31.2</td>
<td>4.0 6.0 25.2</td>
</tr>
<tr>
<td>1500</td>
<td>10.8 28 25.6</td>
<td>10.8 30.4 30.4</td>
<td>17.2 24.4 41.6</td>
<td>7.2 30.0 19.2</td>
<td>15.6 22.0 42.4</td>
</tr>
<tr>
<td>2500</td>
<td>13.2 22 21.2</td>
<td>11.2 32.4 37.6</td>
<td>9.2 18.8 31.2</td>
<td>10.8 16.8 26.0</td>
<td>11.2 34.0 26.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simple Test Figure</td>
<td></td>
<td>Complex Test Figure</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>6.4 15.2 20.4</td>
<td>6.0 17.6 30.4</td>
<td>4.8 27.2 22</td>
<td>5.2 9.2 28.8</td>
<td>2.0 6.4 18.0</td>
</tr>
<tr>
<td>1500</td>
<td>8.8 19.6 20.8</td>
<td>11.2 28.4 23.2</td>
<td>18.4 21.2 40.4</td>
<td>5.2 30.4 22.8</td>
<td>13.6 17.2 29.6</td>
</tr>
<tr>
<td>2500</td>
<td>12.4 20.8 22.8</td>
<td>6.4 30.8 36</td>
<td>10.0 19.6 32.0</td>
<td>8.8 13.2 22.4</td>
<td>8.0 26.0 24.0</td>
</tr>
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<td>------------</td>
<td>------------</td>
<td>------------</td>
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<tr>
<td>Total</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation</td>
<td>2</td>
<td>1165.72</td>
<td>4112.13</td>
<td>3368.31</td>
<td>2504.71</td>
</tr>
<tr>
<td>Deviation × Complexity</td>
<td></td>
<td>88.05*</td>
<td>270.5*</td>
<td>162.02*</td>
<td>223.03*</td>
</tr>
<tr>
<td>Error_α</td>
<td>16</td>
<td>13.24</td>
<td>15.2</td>
<td>20.79</td>
<td>11.23</td>
</tr>
<tr>
<td>Density</td>
<td>2</td>
<td>195.73</td>
<td>573.34</td>
<td>750.71</td>
<td></td>
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<tr>
<td>Density × Complexity</td>
<td></td>
<td>10.63*</td>
<td>20.55*</td>
<td></td>
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<tr>
<td>Error_β</td>
<td>16</td>
<td>18.41</td>
<td>27.9</td>
<td></td>
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</tr>
<tr>
<td>Complexity</td>
<td>1</td>
<td>64.18</td>
<td>34.58</td>
<td></td>
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<tr>
<td>Error_γ</td>
<td>8</td>
<td>31.11</td>
<td>47.4</td>
<td></td>
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<tr>
<td>Deviation × Density</td>
<td>4</td>
<td>59.82</td>
<td>160.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation × Density × Complexity</td>
<td></td>
<td>4.56*</td>
<td>7.45*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error_δ</td>
<td>32</td>
<td>13.14</td>
<td>40.91</td>
<td></td>
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</table>

*p < .05.
complex test figures. Also, neither the interaction of deviation by complexity nor of density by complexity was significant for any of the five subjects. This indicated that as the deviation in the adaptation figure and the complexity of the test figure increased, there was no increase in the recognition time for the test figures; and as the density of the adaptation figures and the complexity of the test figures increased, there was also no increase in the recognition time for the test figures.

The effects which were significant for all five subjects were deviation, density, and the deviation by density interaction. The deviation effect was significant for all subjects. The row means in Table 2 indicate that as the deviation in each adaptation figure increased, the mean difference recognition time increased for the test figures. The density effect was significant for all subjects. The column means in Table 2 indicate that as density in the adaptation figure increased, so did the mean difference recognition time for each test figure. The deviation by density interaction was significant for all subjects. Thus, an interaction existed between density and deviation and the recognition time for a particular test figure increased as density and deviation increased. The means in Table 2 indicate the increase in recognition time as a function of the interaction between deviation and density as they increase.

**Within-subjects Analysis**

Table 2 presents the results for all subjects. It can be seen that for Subject M. C. the deviation effect accounted for 50% of the variance. The density effect accounted for 8% of the variance, while the interaction of deviation by density accounted for 4% of the variance. For Subject P. G. the deviation effect accounted for 68% of the variance. The density effect accounted for 9% of the variance, while the interaction of deviation by density accounted for 5% of the variance. The deviation effect for Subject P. C. accounted for 61% of the variance, the density effect accounted for 13% of the variance, and the interaction of deviation by density accounted for 12% of the variance. For Subject R. P., the deviation effect accounted for 56% of the variance, while the density effect accounted for 2% of the variance. The interaction of deviation by density accounted for 25% of the variance. For Subject M. W. there were four significant effects. M. W. was the only subject in which the interaction of deviation by density by complexity was significant. This effect only accounted for 1% of the total variance. The deviation effect accounted for 41% of the variance. In addition to being the only subject for whom four effects were significant, the density effect for M. W. accounted for a much larger portion of variance than for any other subject, 24%. The interaction of deviation by density accounted for 13% of the variance. The results for these five subjects indicated that the deviation effect was by far the most important element affecting recognition time for simple and complex test figures.
DISCUSSION

The major findings of this study are as follows: first, as angular deviation of the adaptation fields increased, the recognition time for all the test figures increased; second, as the density of the adaptation field increased, the recognition time for all the test figures increased; and third, test figure complexity had no systematic effect on recognition time.

Previous adaptation studies (Gilinski & Cohen, 1972; Andrews, 1965; Houlihan & Sekuler, 1968) have consistently shown that test figure recognition thresholds vary according to the nature of the adaptation field. For example, Gilinski and Cohen (1972) found both reaction time and recognition threshold increase as a function of the extent to which adaptation and test fields were similarly oriented. Such results have been interpreted as indicating adaptation of contour-specific "property analyzers" of the type first reported by Hubel and Wiesel (1962). However, the method employed by such studies inevitably confounds two factors, orientation similarity and retinal locus. That is, the magnitude of any adaptation effect could be due to either peripheral fatigue, i.e., adaptation of identical visual receptors, more centralized adaptation, i.e., fatigued "property analyzers," or to a combination of both. A critical test of the property analyzer model would then involve an independent testing of these two factors.

The present study has achieved this result by an independent manipulation of the variables of density and deviation. A case in point involves the low deviation and variable density conditions. An angular deviation of 0° means that the adaptation field consists essentially of a set of vertical lines. The test figures, on the other hand, contain few vertical lines (less than 5%). Thus, any increase in recognition thresholds as a function of density must be due to factors other than changes in the relative orientation of test and adaptation fields. The fact that a significant adaptation effect results with no change in the relative orientation of the test and adaptation fields argues strongly for a fatigue-like effect independent of contour similarity. That is, simply filling the visual field with any stimulus will inhibit subsequent recognition of other stimuli, provided that the sites of stimulation overlap.

The present study also indicated a relationship between angular deviation and recognition thresholds for the test figure. That is, as the range of angles in the adaptation field increased, recognition thresholds were raised. For a particular density level, this may be interpreted as follows: increasing the angular range from 0° has the effect of increasing angles, that is, the lines which comprise the adaptation field do not intersect in the 0° condition but do in all others. The greater the range of angles formed by the intersection of component lines, the greater the probability is that angles will be generated which in fact duplicate the angles found in the test figures. The difference will be that these
angles will be randomly dispersed throughout the adaptation field and would seldom exactly overlap identical test-figure contours.

The fact that an adaptation effect is enhanced as the range of angles produced is increased suggests that angular similarity *per se* is a critical factor, even when stimulation sites are not identical. That is, by increasing the range of angles in the adaptation field, the probability of generating angles identical to those comprising the test figures also increases. Hence, the increased adaptation effect is apparently due to increasing angular similarity between test and adaptation fields, independent of stimulation sites.

These results thus suggest that contour adaptation involves at least two processes: a general, probably peripheral effect due to the fatigue of visual receptor units, and a more specific effect generated by the similarity between test figure and adaptation contours, independent of the site of stimulation. Previous studies have reported adaptation effects but have inevitably confounded contour similarity with stimulation site. The present study lends support to the notion that specific stimulus properties may undergo adaptation even when the adapting figure does not occupy the same portion of the visual field as the test figure.

REFERENCES


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