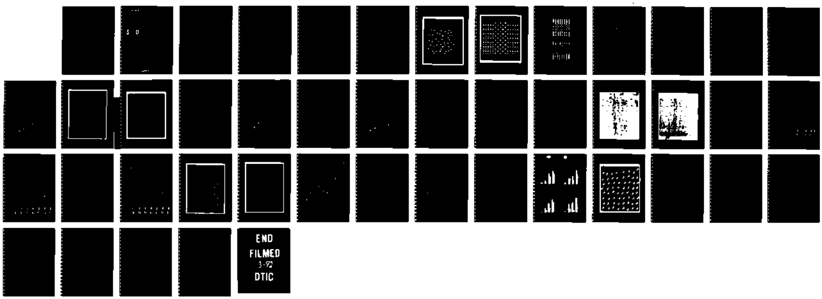
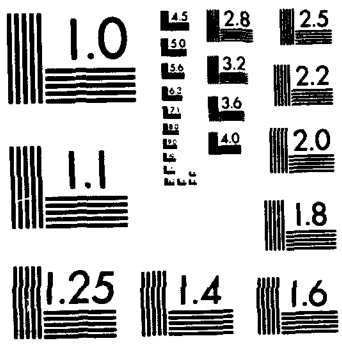
AD-A247 173 VISUAL PROCESSING IN TEXTURE SEGREGATION(U) OREGON UNIV 1/1
EUGENE DEPT OF PSYCHOLOGY J BECK 17 DEC 91
AFOSR-TR-92-0075 AFOSR-88-0323

UNCLASSIFIED NL




1.0
4.5
5.0
5.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

(2)

VISUAL PROCESSING IN TEXTURE SEGREGATION

Final Report AFOSR Grant 88-0323
(September 1, 1988 - September 30, 1991)

Jacob Beck

Department of Psychology
University of Oregon
Eugene, OR 97403

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 92 0075
6a. NAME OF PERFORMING ORGANIZATION Department of Psychology University of Oregon 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Directorate of Life Sciences Air Force Office of Scientific Research
6c. ADDRESS (City, State, and ZIP Code) Eugene, Oregon 97403-0237	7b. ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332-6448
8a. NAME OF FUNDING / SPONSORING ORGANIZATION AFOSR 8b. OFFICE SYMBOL (If applicable) NL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-88-0323
8c. ADDRESS (City, State, and ZIP Code) Building 410 Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2313; TASK NO. A9; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Visual Processing in Texture Segregation

12. PERSONAL AUTHOR(S)
Jacob Beck

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 9/1/88 TO 9/30/91	December 17, 1991	43

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Vision, texture segregation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Two types of texture segregation occurs. Preattentive texture segregation has been shown to occur as a result of differences in the outputs of Gabor filters that operate on intensity values and as a result of the grouping of discrete elements through edge alignment and lightness similarity. Texture segregation based on these properties occurs preattentively. A second type of texture segregation appears to depend on attention. Texture segregation based on the 3D interpretation of projected shapes appears to require a focussing of attention. Attention acts to trigger texture segregation. Attention is required to see a 2D figure as three-dimensional. The 3D interpretation is propagated in parallel or rapidly to the other figures in the pattern and texture segregation occurs in terms of the differences in the perceived orientations off the 3D figures. A necessary condition for texture segregation is the rapid processing of stimulus differences. Texture segregation does not occur if discrimination of the relevant stimulus differences requires sequential attentional processing.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. John Tangney	22b. TELEPHONE (Include Area Code) (202) 767-5021 / 22c. OFFICE SYMBOL AFOSR/NL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

1. ABSTRACT

Previous research showed that the outputs of 2D Gabor filter can account for much of the segregation of a periodic visual display into regions (Sutter, Beck, & Graham, 1989). Two nonlinearities were shown also to occur (Graham, Beck, & Sutter, 1989; in press). One nonlinearity was an intensity dependent nonlinearity which can be accounted for by sensory adaptation occurring before the channels or by a compressive intracortical interaction among the channels (see Grossberg & Mingolla, 1985). The second nonlinearity was a rectification-like nonlinearity that is like that presumed to occur in complex cells (Spitzer & Hochstein, 1988). During the first year of AFOSR Grant 88-0320, research was completed showing that grouping processes, as well as the outputs of spatial-frequency/orientation channels, yield effortless spontaneous segregation. Two types of grouping were shown to yield effortless texture segregation: (1) the grouping of discrete elements into a line-line like pattern through alignment and equal spacing of the elements, and (2) the grouping of intermixed elements into subpopulations through lightness similarity. The results of these studies are described in Beck, Rosenfeld, & Ivry (1989), and Beck, Graham, & Sutter (1990).

During the second and third years of AFOSR Grant 88-0320, the roles of spatial-frequency channels and grouping in texture segregation were further studied. Patterns were constructed in which differences in the outputs of Gabor filters fail to account for the perceived segregation. Perceived segregation was, however, predicted by the outputs of concentric DOG and Type I filters (Ts'o & Gilbert, 1988). The discrepancy between the DOG and Gabor filters suggests the possibility that the concentric filters are not really measuring the properties yielding perceived segregation. Further studies have shown that this is the case. Perceived segregation is a function of the salience of the lightness and hue differences and is not explainable as a direct consequence of the differences in receptive-field outputs. Experiments also compared the properties of 2D and 3D figures yielding effortless segregation. Changes in the orientations of a stimulus in which the slopes of the component features do not change, e.g., a 180 degree rotation of a stimulus, yields stronger segregation with perceived 3D figures than with perceived 2D figures. We hypothesize that perceived segregation is the result of grouping processes. A 3D representation makes explicit the orientations of object surfaces enabling the grouping of 3D figures by the similarity of their surface orientations, e.g., the directions of their surface normals.

Beck & Ambler (1972, 1973) hypothesized that effortless texture segregation requires parallel or rapid processing across the visual field and fails to occur if discrimination requires focussed attention to examine the elements in a display in an attentional sequential manner. Parallel or rapid processing can occur without attention or with distributed attention when texture segregation is given by differences in spatial-frequency channel outputs and by salient differences in simple properties such as lightness and hue. In contrast, attention, at least under some circumstances, appears to be required for perceiving a 2D pattern as three-dimensional. The segregation of convex and concave shapes based on shading gradients takes several seconds and appears to require focussed attention (Rammachnadran, 1990). We hypothesize that attention acts as a trigger. Attention is required to interpret a 2D pattern as three-dimensional. The three-dimensional interpretation is a global interpretation and is immediately propagated to the other figures in a pattern as soon as soon as it is achieved with one figure. Texture segregation occurs because the differing 3D orientations of the figures are encoded in parallel or very rapidly and does not depend on sequential attentional processing.

2. RESEARCH SUMMARY

2.1 Introduction

Much of the experimental data in texture segregation can be explained by spatial-frequency channels operating on image intensities and preattentive grouping processes operating on elementary properties such as edges and lightness values. Spatial-frequency channels and preattentive grouping processes may be distinguished by how they are affected by stimulus variables. First, an approximate area x contrast tradeoff occurs when texture segregation is a direct consequence of the way in which intensities in a texture pattern stimulate spatial-frequency channels. Such a trade-off fails to occur when texture segregation is a consequence of preattentive grouping processes. Second, the relevant variable for spatial-frequency channels is stimulus contrast whereas the relevant variable for similarity grouping is perceived lightness. Beck, Graham and Sutter (1990) reported that the perceived segregation of two intermixed populations of squares is approximately a single-valued function of the differences in the perceived lightnesses of the squares The stimulus display is illustrated in Figure 1. Alternatively, the perceptual segregation of a pattern resulting from differences in the arrangement of the two types of elements composing a pattern is more nearly a single-valued function of the contrasts of the squares An example of an element arrangement pattern is shown in the Figure 2. The light and dark squares form stripes in the top and bottom regions and checks in the center region. Perceived lightnesses are the same for a given set of squares whether they are in texture regions or in intermixed populations.

Third, the receptive fields showing strikingly different outputs to the different arrangements of the squares in the striped and checked regions in the pattern are the large receptive fields that are sensitive to the fundamental frequency of the striped and checked patterns. These large receptive fields are not sensitive to edge alignment and we have found that the segregation of a pattern is not decreased by the misalignment of edges. Figure 3 shows examples of aligned and misaligned element-arrangement patterns. On the other hand, Beck, Rosenfeld and Ivry (1989) showed that edge alignment facilitated the perceived segregation of a line of squares embedded in a background of the same squares (Figure 4). Sutter, Beck & Graham (1989) proposed a model based on Gabor filters to explain the perceived segregation of tripartite patterns. A principal purpose of the experiments was to test whether this type of model can explain line segregation. Experiment 6 shows that the outputs of Gabor filters fail to account for line segregation. Taken together, the results of these experiments indicate strongly that other factors in addition to spatial density such as the alignment of element edges and edge length influence line segregation.

2.2 I-Beam, Grating, Center-Surround Patterns

We have conducted experiments which further examine the contribution of spatial frequency outputs and lightness differences to texture segregation. The two types of elements composing a pattern were equal in size (24 pixels on a side--1 pixel=1.08 minutes) and were comprised of the same two luminances. What distinguished the elements in a discrepant quadrant from those in the non-discrepant quadrants of a pattern was a reversal of their contrasts. i.e., the light and dark areas of the elements were interchanged. The light and dark areas composing an element were of equal area.

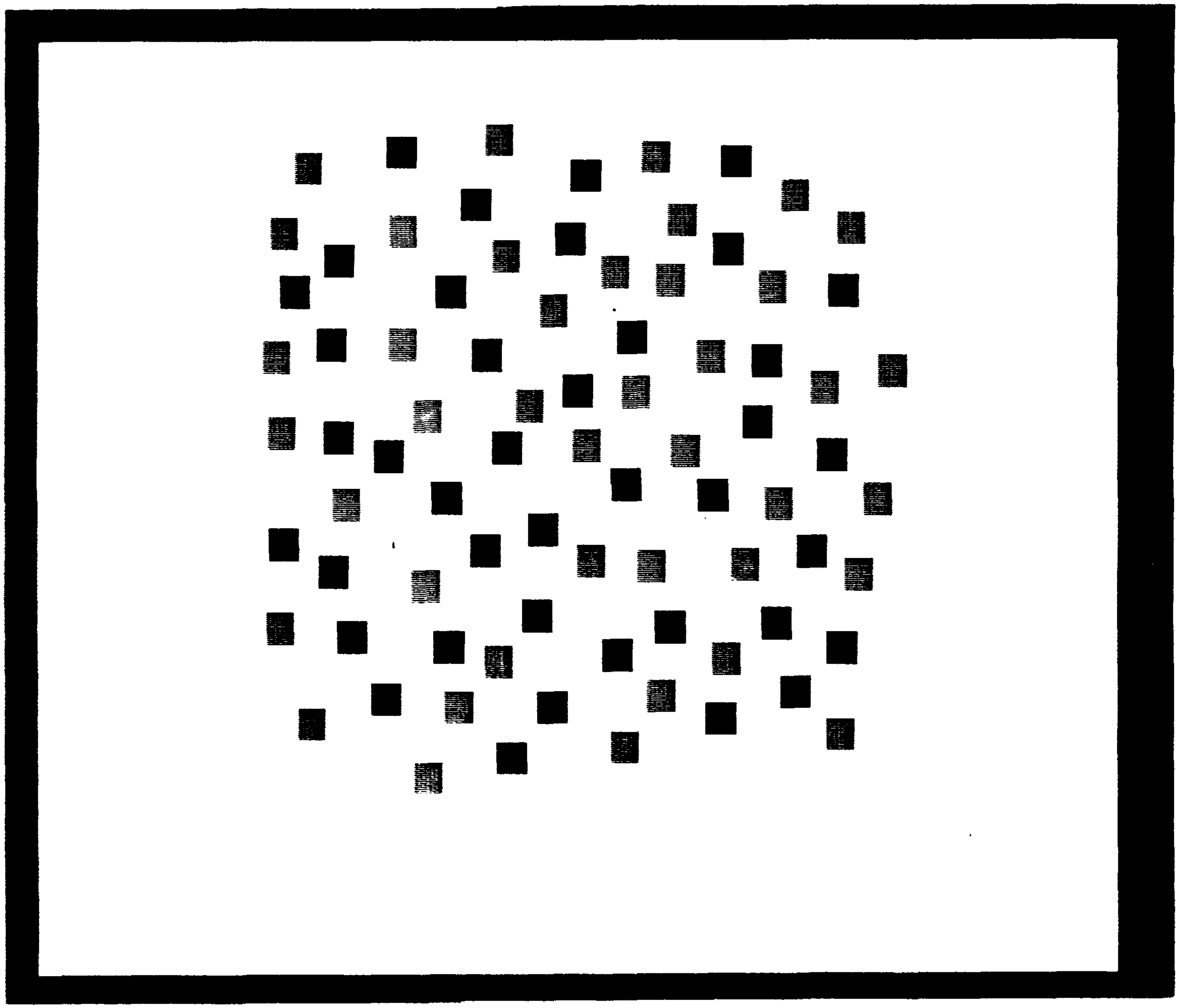


Figure 1

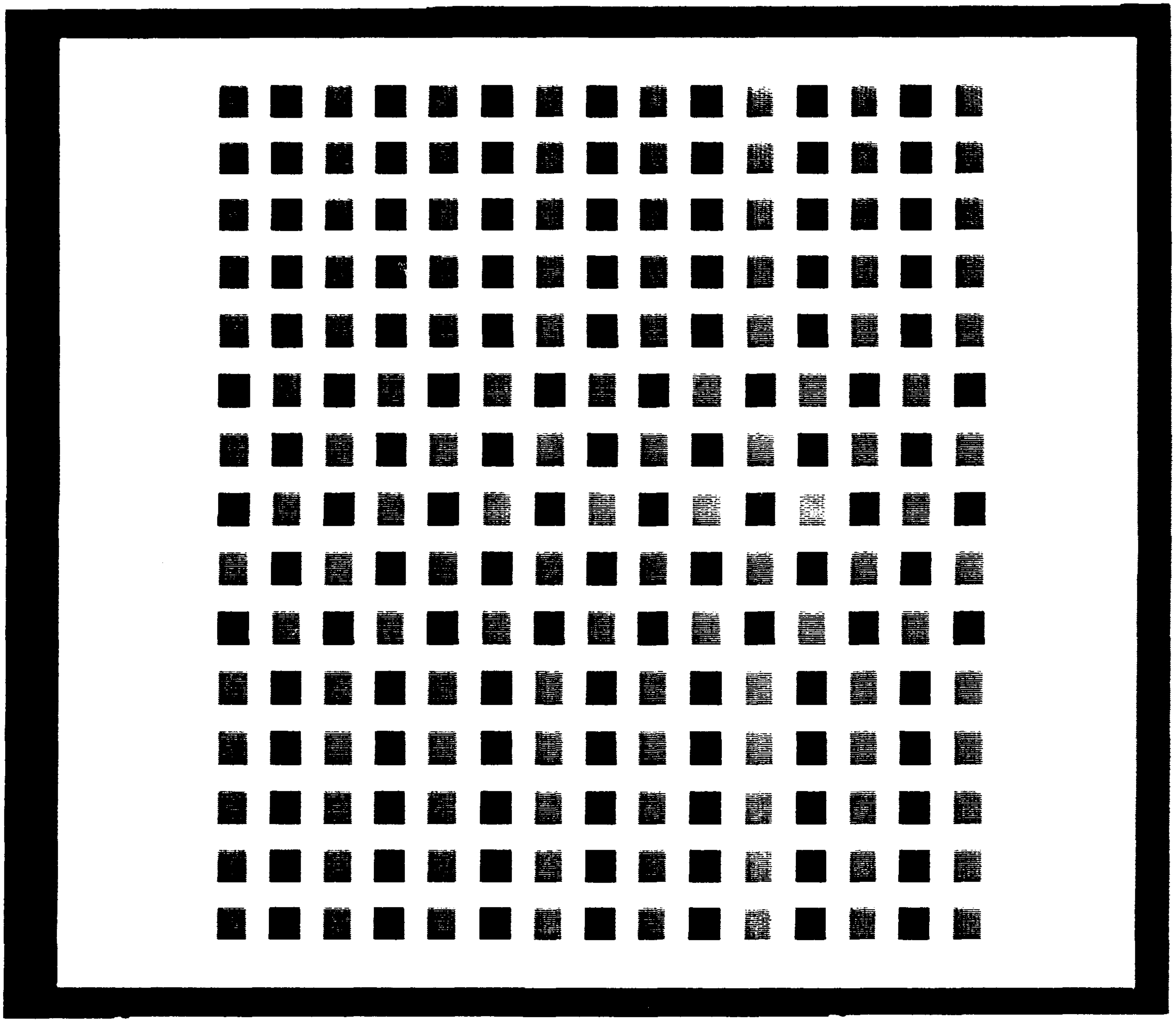


Figure 2

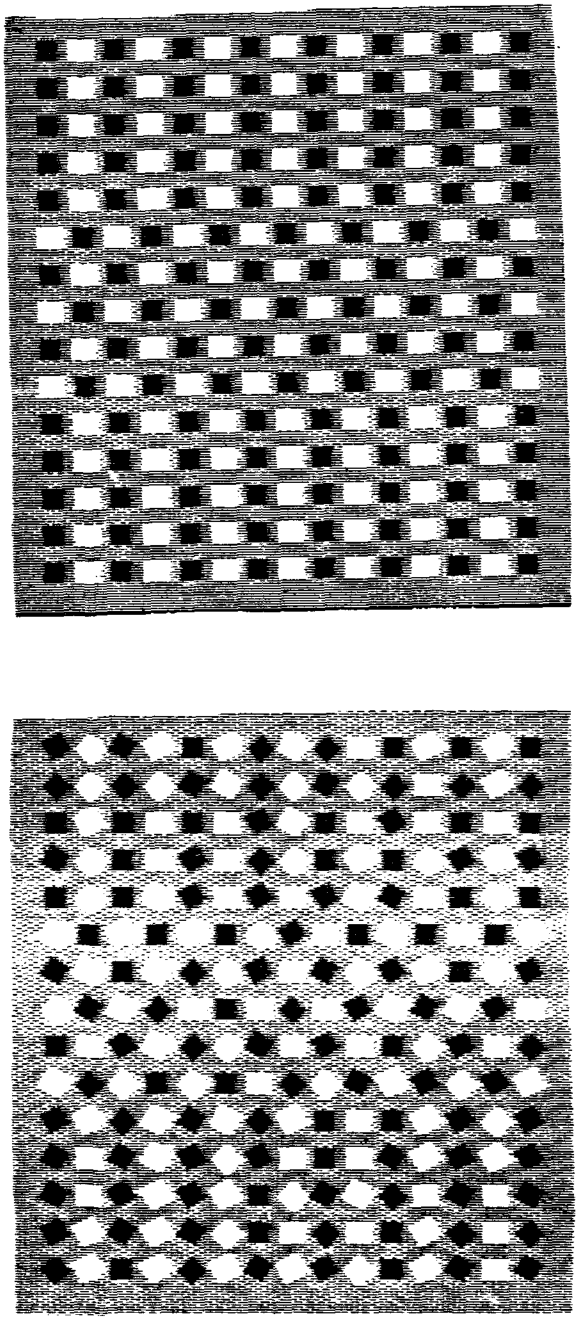


Figure 3

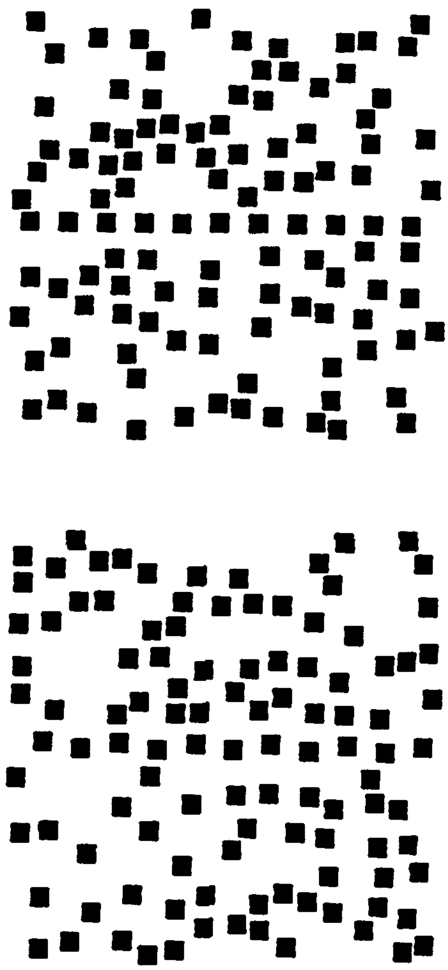


Figure 4

The top row in Figure 5 illustrates the elements in the discrepant quadrant, and the bottom row the elements in the non-discrepant quadrants. There were nine pairs of elements. There were two pairs of elements composed of bars. In the first pair, the bars were the same through out the display, the top bar was dark and the bottom bar was light. In the second pair, the top bar was dark and the bottom bar light in the discrepant quadrant; in the non-discrepant quadrants the top bar was light and the bottom bar dark (The bars were 12 x 24 pixels.). There were three pairs of elements with a pedestal of increasing height. The third pair of elements had a low pedestal (The pedestal was 2 x 12 pixels.); the fourth pair a high pedestal (The pedestal was 20 x 12 pixels.) and fifth pair a pedestal to the top (The pedestal was 22 x 11 pixels.). The sixth pair of elements were I-Beam figures (The center beam was 18 x 8 pixels and the crossbeam was 3 x 24 pixels.), and the seventh pair gratings (The center area was 24 x 12 pixels and flanking areas of 24 x 6 pixels.). The eighth pair of elements were rectangles surrounded on three sides, labeled Center-3 (The rectangle was 18 x 16 pixels.) and the ninth pair a square surrounded on four sides, labeled Center-4 (The square was 17 x 17 pixels). In all patterns, the arrangements of the elements were the same. Figure 6 illustrates the I-Beam and Figure 7 the Center-4 patterns with the discrepant quadrant in the upper left.

A subject rated the perceived segregation of the discrepant quadrant on a scale from 0 to 4. A rating of 4 indicated that the discrepant quadrant segregated strongly and a rating of 0 indicated that the discrepant quadrant failed to segregate. The stimuli were displayed for 1000 msec. The discrepant quadrant appeared equally often in each of the four corners. The horizontal axis in Figure 8 shows the different patterns and the vertical axis the mean of subjects' segregation ratings. The luminance of the background was 9.8 ft-L., the lower intensity area in an element 14.3 ft.-L. (a contrast of .35), and the higher intensity area in an element 16.3 ft.-L. (a contrast of .54). The perceived segregation of the Center-4 and the I-Beam patterns are strikingly different. The Center-4 pattern segregated strongly, the mean rating was 3.3, while the I-Beam segregated weakly, the mean rating was 1.6.

We examined whether the outputs from DOG and Gabor filters predicted the segregation ratings. The diameters of the DOG filters increased in steps of powers of the square root of 2 from 11 to 189 pixels giving a total of 11 channels. The Gabor filters increased in steps of powers of the square root of 2 from .25 to 16 cycles/degree for three different orientations--vertical, 45 degrees, and horizontal giving a total of 39 channels. The modulation of outputs in each channel was assessed by computing the standard deviation of the outputs for different spatial positions of the weighting function. The difference between each channels standard deviation to the discrepant and non-discrepant quadrants yielded a within channel difference for each stimulus. The within-channel differences were weighted by the contrast sensitivity function (see Sutter, Beck & Graham, 1989 for a detailed description of the computations).

Figure 9 shows the outputs of the DOG filters to the discrepant and non-discrepant quadrants. The difference between each channels standard deviation to the discrepant and non-discrepant quadrants yielded a within channel difference for each stimulus. The vertical axis plots the square-root of the sum of the squares of the weighted within channel differences. Plotted are the statistics computed from different measures of output modulation. ("Normal" refers to all the outputs. "Positive" to the outputs greater than zero. "Negative" to the outputs less than zero. "Half-Wave Rectification (on-cell)" to setting the negative outputs to zero. "Half-Wave Rectification (off-cell)" to setting the positive outputs to zero. "Full-Wave Rectification" to taking

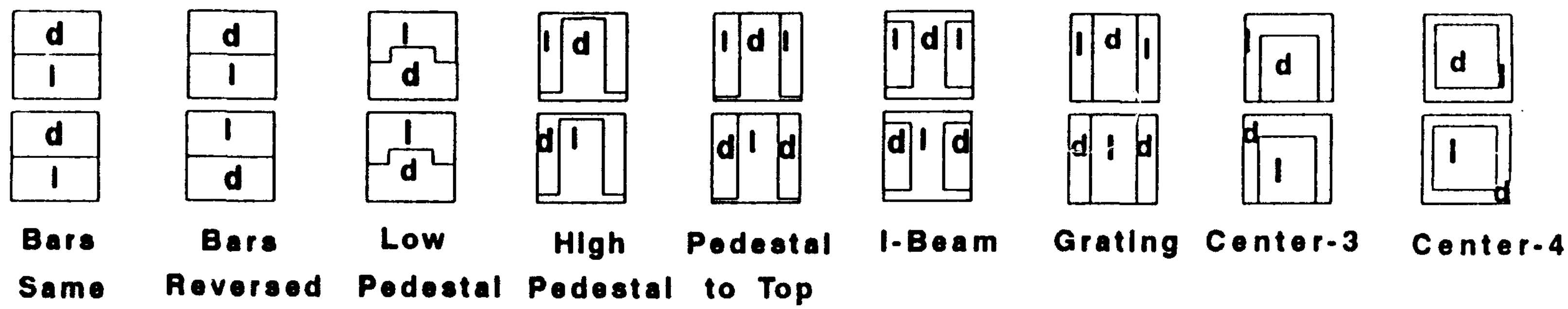

Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 5

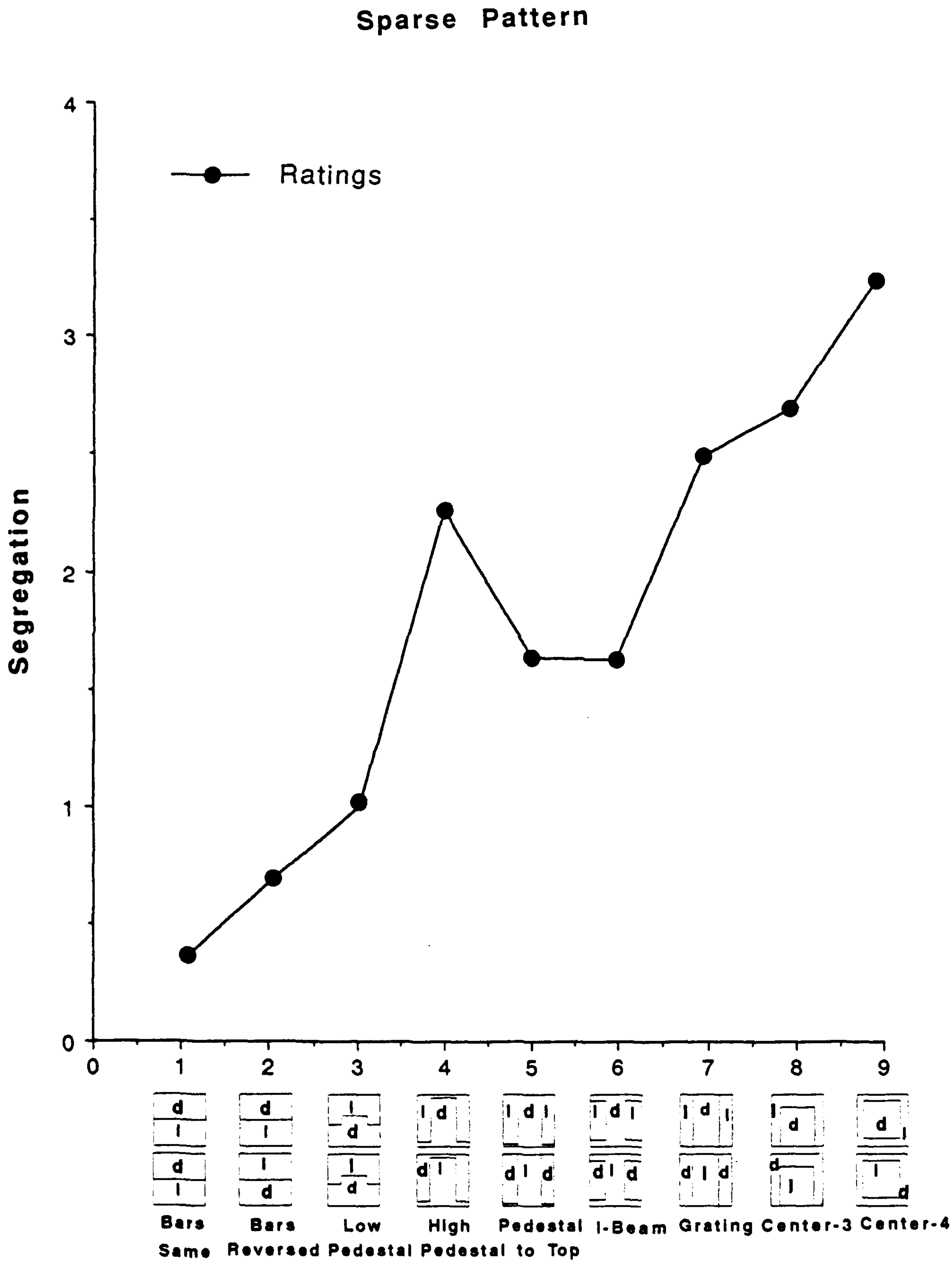
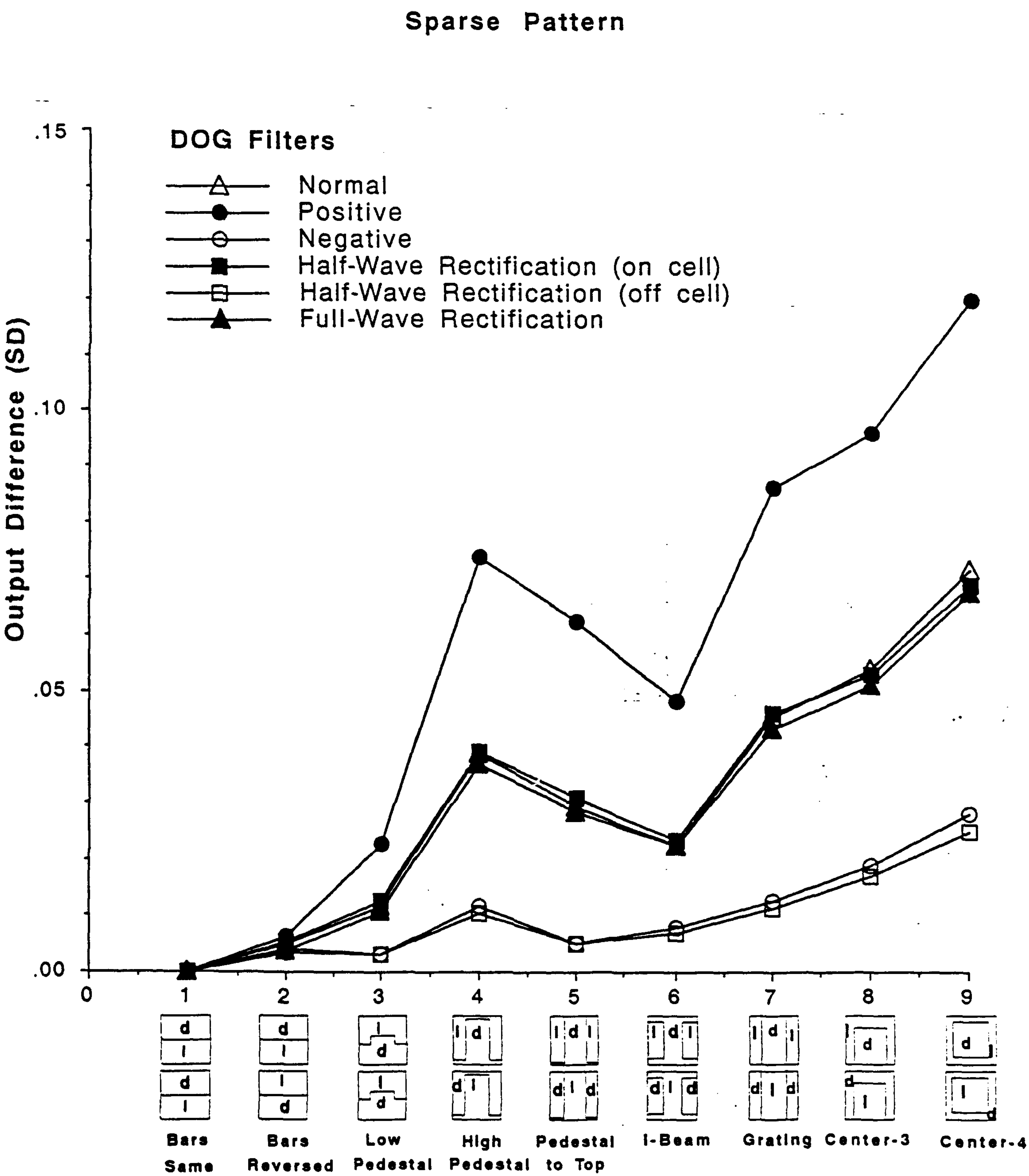

Sparse Pattern
Ratings
Segregation
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 8



Sparse Pattern
DOG Filters
Normal
Positive
Negative
Half-Wave Rectification (on cell)
Half-Wave Rectification (off cell)
Full-Wave Rectification
Output Difference (SD)
.15
.10
.05
.00
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 9

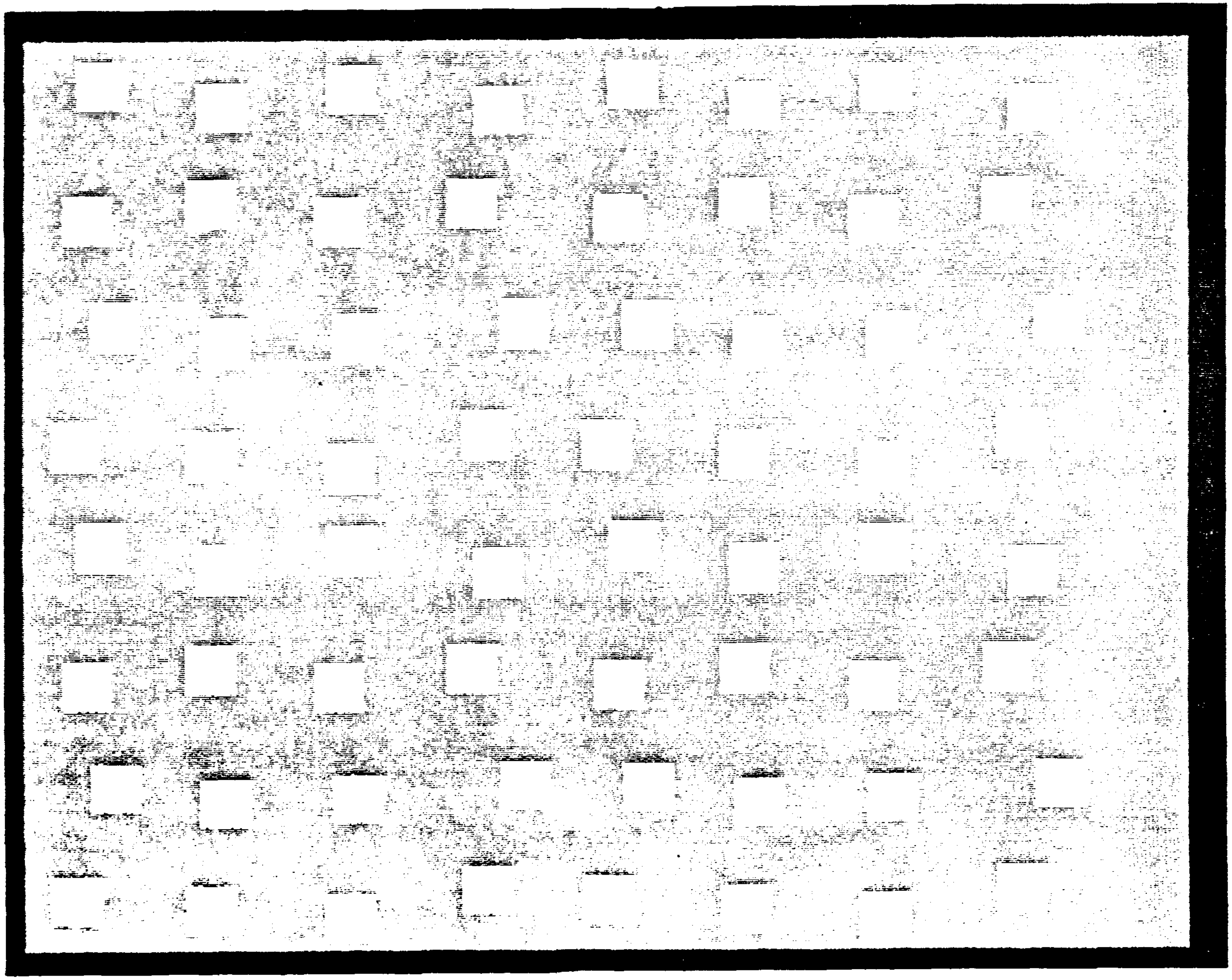


Figure 6

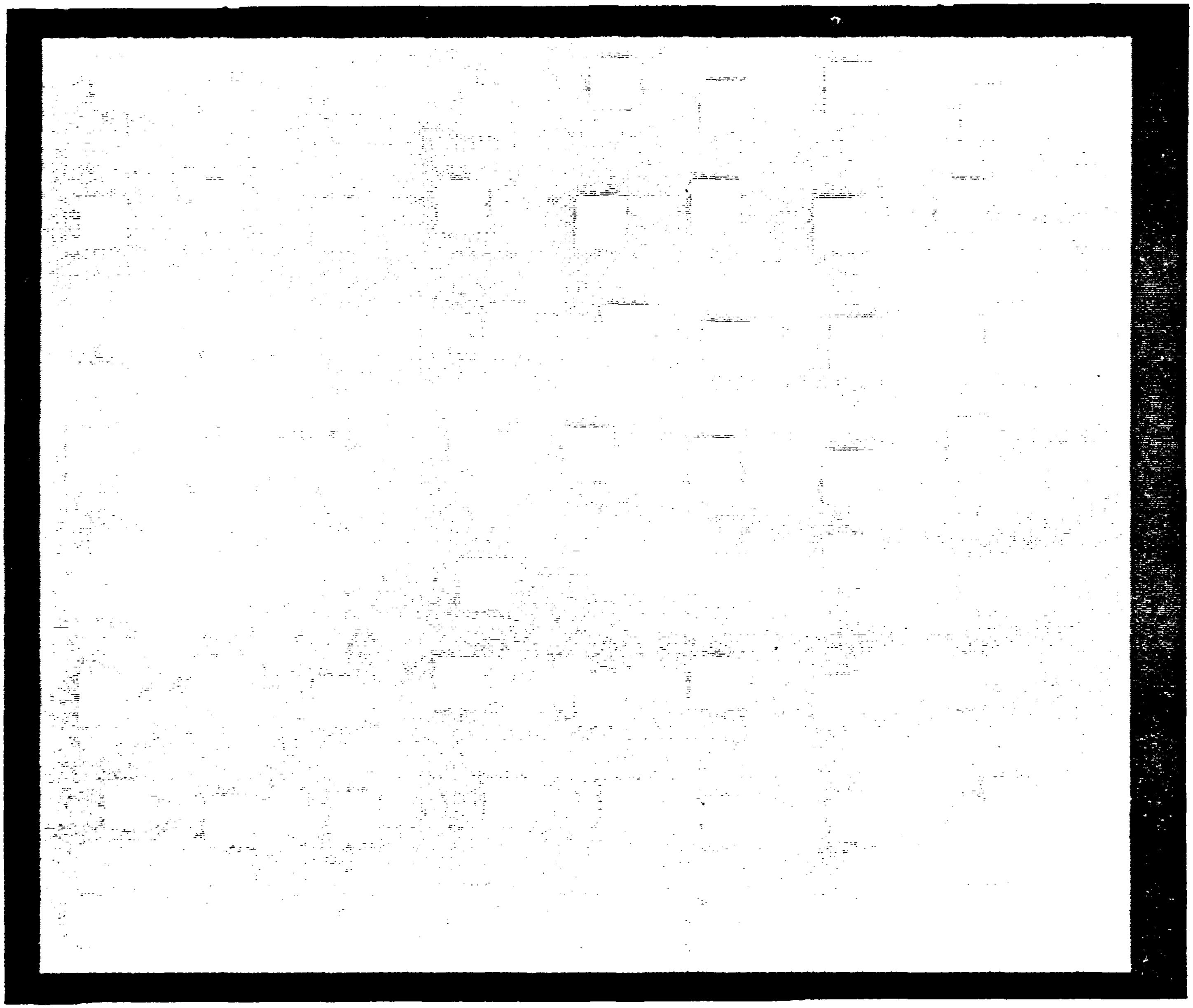


Figure 7

the absolute value of the outputs.) All correctly predict the order relations in the data. Figure 10, in contrast, shows that the outputs of the Gabor filters fail to predict the perceived segregation ratings.

Similar results were obtained in a second study in which the density of elements in a pattern was varied. Sparse and dense patterns were presented. The dense patterns had 32 elements in each quadrant. The sparse patterns, as in the experiment just described, had 16 elements in each quadrant. Figure 11 shows the perceived segregation ratings for the sparse and dense patterns. The segregation ratings for the dense patterns tend to be greater than for the sparse patterns. The shapes of the overall curves are very similar. Figure 12 shows the predicted segregation when the dense patterns were convolved with the DOG filters. The overall pattern of the outputs are similar to those of the sparse pattern. Consistent with subjects judgments of perceived segregation, the outputs for the dense pattern tend to be greater than for the sparse pattern.

2.3 Isoluminant Patterns

In a third study, we investigated whether the outputs of concentric receptive fields predict perceived segregation when the elements were composed of red and green areas of equal luminance. The elements composing the patterns were the same as in Experiment 1 and are shown below the horizontal axis in Figure 13. The red and green areas of the elements in the non-discrepant quadrants were the reverse of those in the discrepant quadrant. The patterns were presented on white and black backgrounds. The perceived segregation was similar to that with achromatic elements. The Center-4 pattern segregated strongly (mean ratings of 3.7 and 3.8 with black and white backgrounds respectively) while the I-beam segregated weakly (mean ratings of 1.5 and 1.2 with black and white backgrounds respectively). As might be expected, the results do not depend on strict isoluminance. The overall shape of the function remained the same when luminance differences were added to the hue difference.

We convolved the patterns with concentric filters modeled after the Type 1 center-surround cells described by Ts'o and Gilbert (1988). These cells have an opponent color center-surround organization-- e.g., red is excitatory in the center and green is inhibitory in the surround. However, red in the surround and green in the center have no effect. The sizes of the Type 1 filters were the same as the DOG filters. Figure 14 shows that the combined within channel standard deviation differences are successful in predicting the order of perceived segregation.

2.4 DOG and Gabor Filters

Though the Dog and Type I filters predict the perceived segregation ratings, the discrepancy between the DOG and concentric filters suggests that the correspondence between perceived segregation and the outputs of the concentric filters is accidental. Three observations supported this suggestion.

First, the outputs of the DOG filters predicting the perceived segregation do not correspond with the perceptual experience. The segregation of the Center-4 stimulus appears to be the result of the salience of the dark squares in the discrepant quadrant and light squares in the non-discrepant quadrants. The output differences predicting the greater perceived segregation of the Center-4 pattern are, however, not the result of the filters responding to the center square in the

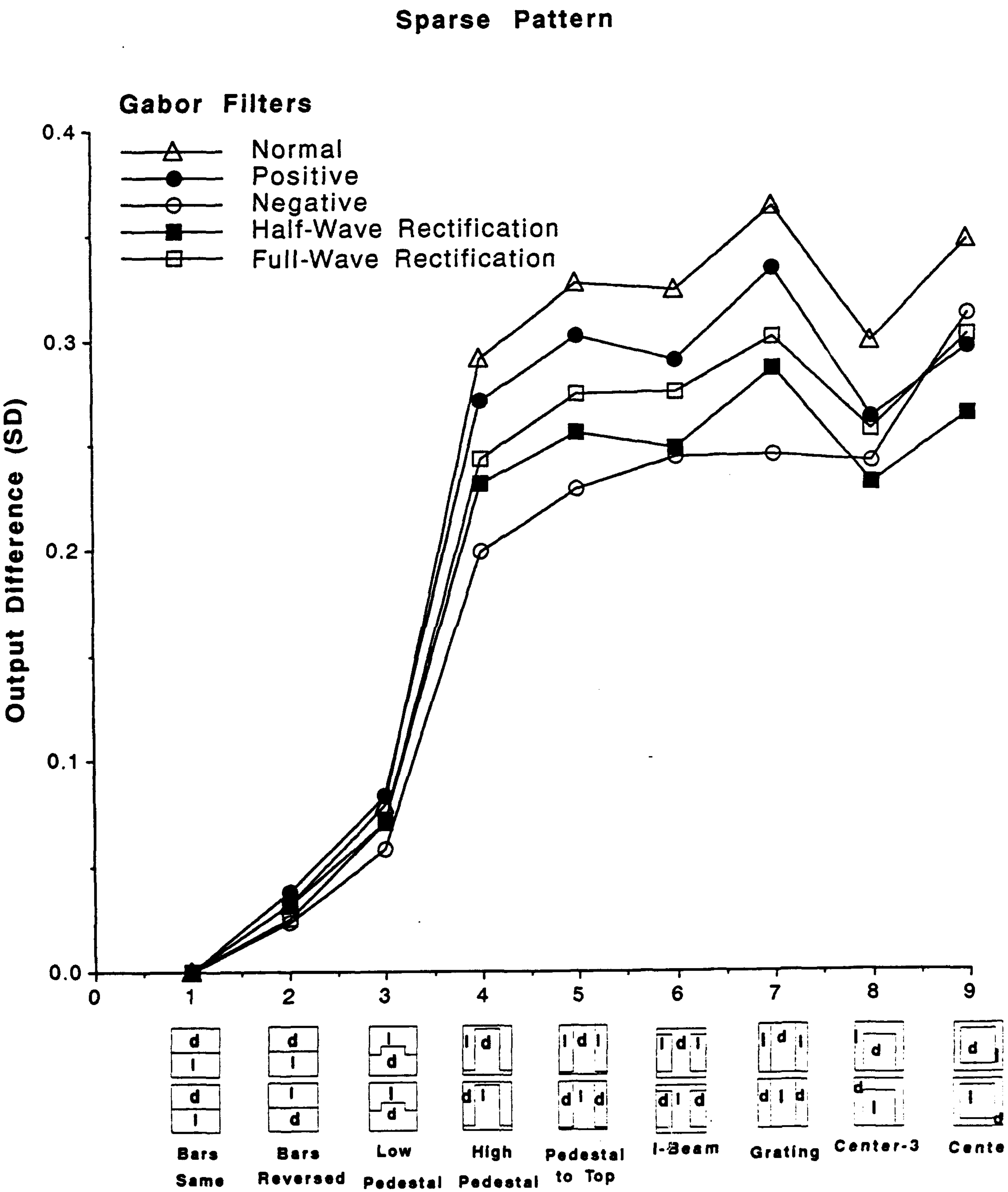

Sparse Pattern
Gabor Filters
Normal
Positive
Negative
Half-Wave Rectification
Full-Wave Rectification
Output Difference (SD)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Cente

Figure 10

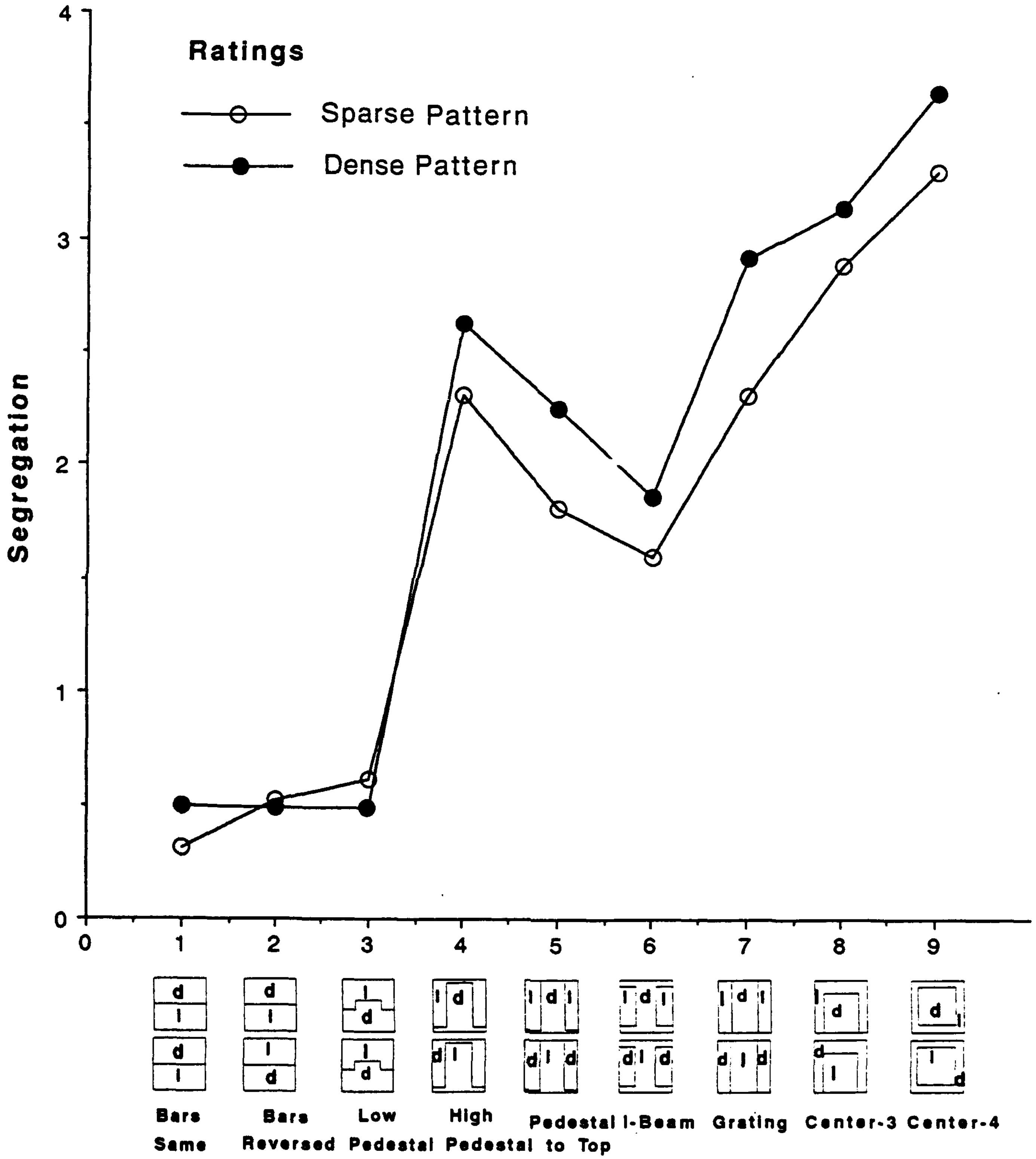

Ratings
Sparse Pattern
Dense Pattern
Segregation
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 11

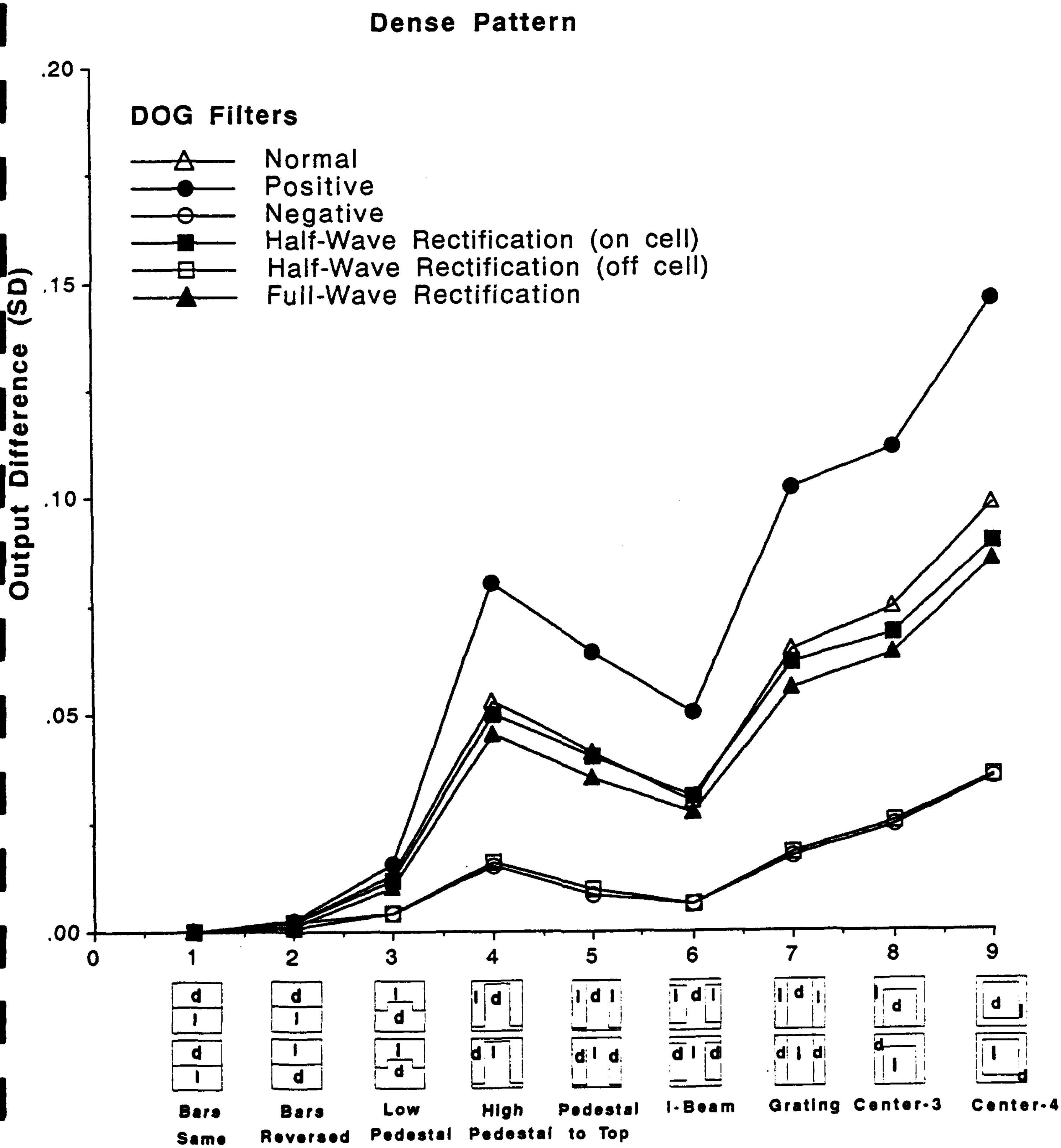

Dense Pattern
DOG Filters
Normal
Positive
Negative
Half-Wave Rectification (on cell)
Half-Wave Rectification (off cell)
Full-Wave Rectification
Output Difference (SD)
.20
.15
.10
.05
.00
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 12

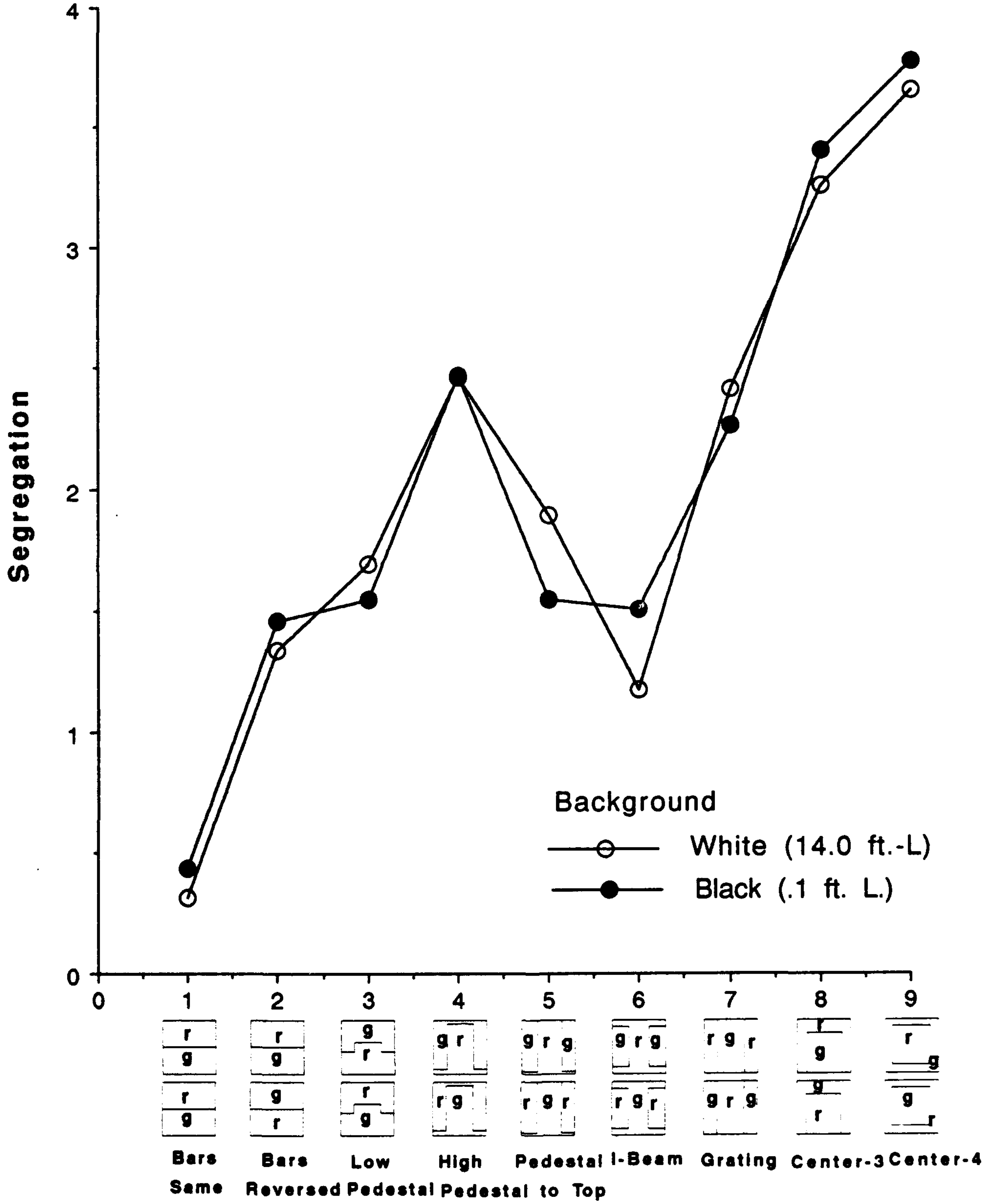

Segregation
0
1
2
3
4
0 1 2 3 4 5 6 7 8 9
Background
White (14.0 ft.-L)
Black (.1 ft. L.)
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 13

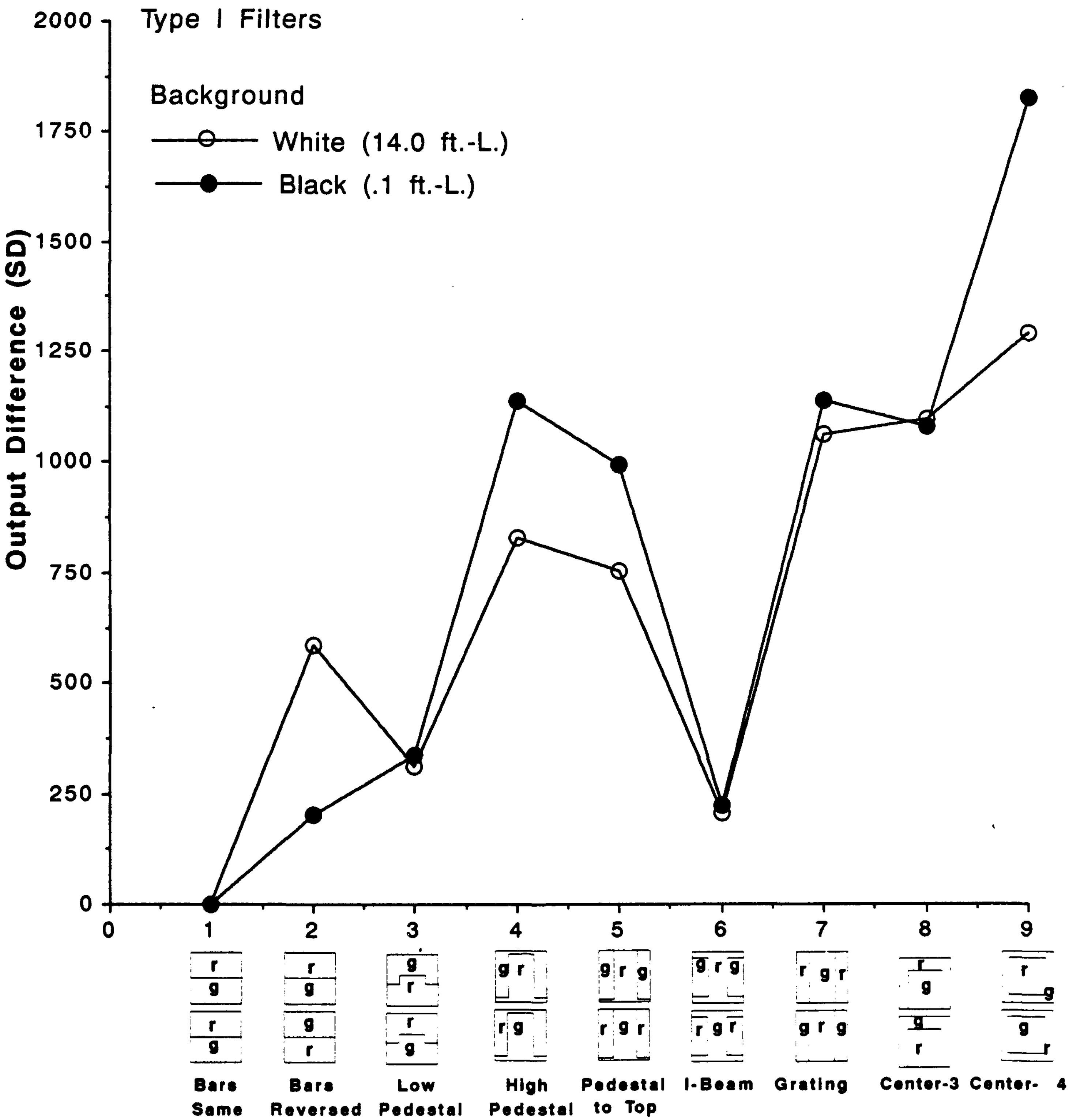

Type I Filters
Background
White (14.0 ft.-L.)
Black (.1 ft.-L.)
Output Difference (SD)
2000
1750
1500
1250
1000
750
500
250
0
0
1
2
3
4
5
6
7
8
9
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center- 4

Figure 14

Center-4 element. They arise from the responses of the 11 and 23 pixel diameter DOG filters to the edges and corners of the Center-4 element. Figure 15 shows that the output is greater to the edges and corners of the Center-4 discrepant element than to the Center-4 non-discrepant element. A higher intensity in the picture means a larger positive output. Figure 16 shows that the outputs of the 23 pixel filter to the discrepant and non-discrepant elements in the I-Beam pattern are more similar.

Second, there is an intriguing correspondence between perceived segregation and the compactness of the regions composing the texture elements. Compactness is given by the square of the perimeter divided by the area of a region. Perceived segregation occurs strongly when there is a large difference in the compactness of the two regions composing a texture element, and occurs weakly when the compactness of the two regions making up a textured element are approximately equal. Figure 17 plots the ratio of the compactness values of the two regions composing a texture element. (The smaller compactness value was placed in the denominator.) The compactness ratios were linearly transformed so that the lowest compactness ratio, 1.0, for the Bars-Same element was made equal to the segregation rating for Bars-Same pattern and the highest compactness ratio, 2.4, for the Center-4 element was made equal to the segregation rating of the Center-4 pattern in Experiment 1. For comparison, the perceived segregation ratings in Experiment 1 are also plotted. The overall similarity to the perceived segregation ratings in Experiment 1 suggests that perceived segregation is affected by the difference in the compactness of the two regions making up a texture element.

Third, though each of the texture elements are composed of equal areas of the same two lightness values, the elements differ in their impression of prevailing lightness. For example, the Center-4 element in the discrepant quadrant looks prevailingly dark, and in the non-discrepant quadrants prevailingly light. In contrast, the I-beam elements look light and dark in both the discrepant and non-discrepant quadrants. It is possible that perceived segregation is a function of this difference in the prevailing lightnesses of the discrepant and non-discrepant quadrants in a texture pattern. For elements composed of two equal-area regions, it is not unreasonable to expect that the lightness of the more compact region would dominate the perception of overall lightness.

2.5 Irregular Patterns: Background Between

We have investigated the hypothesis that it is the prevailing difference in lightness that yields strong perceived segregation in several experiments. The elements in one experiment are shown below the horizontal axis in Figure 18. The top row shows the light (l) and dark (d) areas composing an element in the discrepant quadrant and the bottom row shows the light and dark areas composing an element in the non-discrepant quadrants. The areas of the light and dark areas of an element were equal. Figure 18 plots perceived segregation in an experiment in which the luminance of the background was midway between the luminances of the light and dark areas composing each element. The background luminance was 10 ft.-L.; the high and low luminances 20 and 0 ft.-L (contrasts of +1.0 and -1.0). The horizontal axis plots the average distance between the vertical bars. In general, the greater the separation between the vertical bars the stronger is the segregation. The exception is the sixth pair of elements in which we inadvertently lined up the horizontal extensions yielding strong subjective contours. Figure 19 shows the predicted segregation ratings when the patterns are convolved with the DOG filters. Unlike the I-Beam set of patterns, none of the output measures correctly predict the order relations in the data. Figure

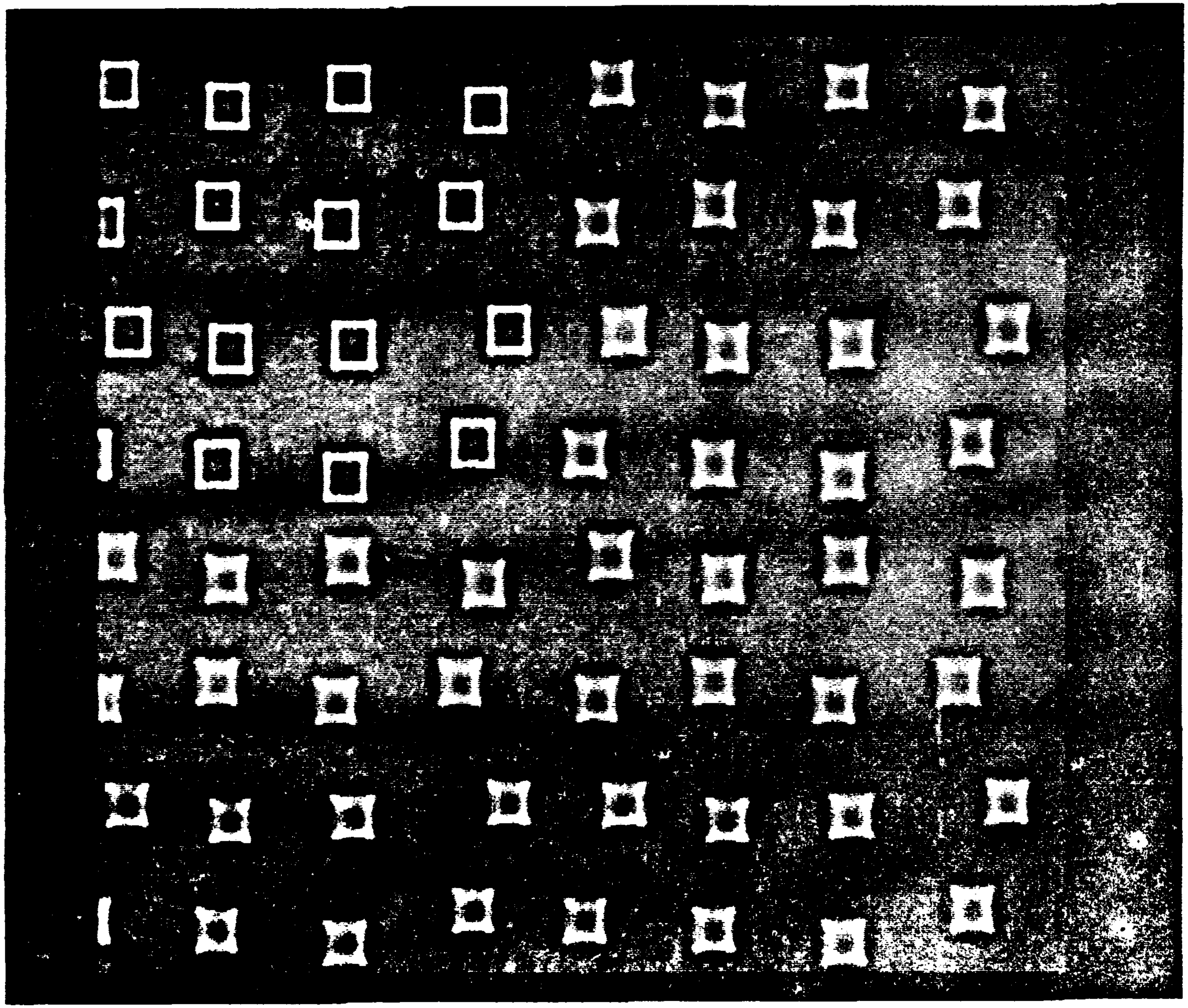


Figure 15

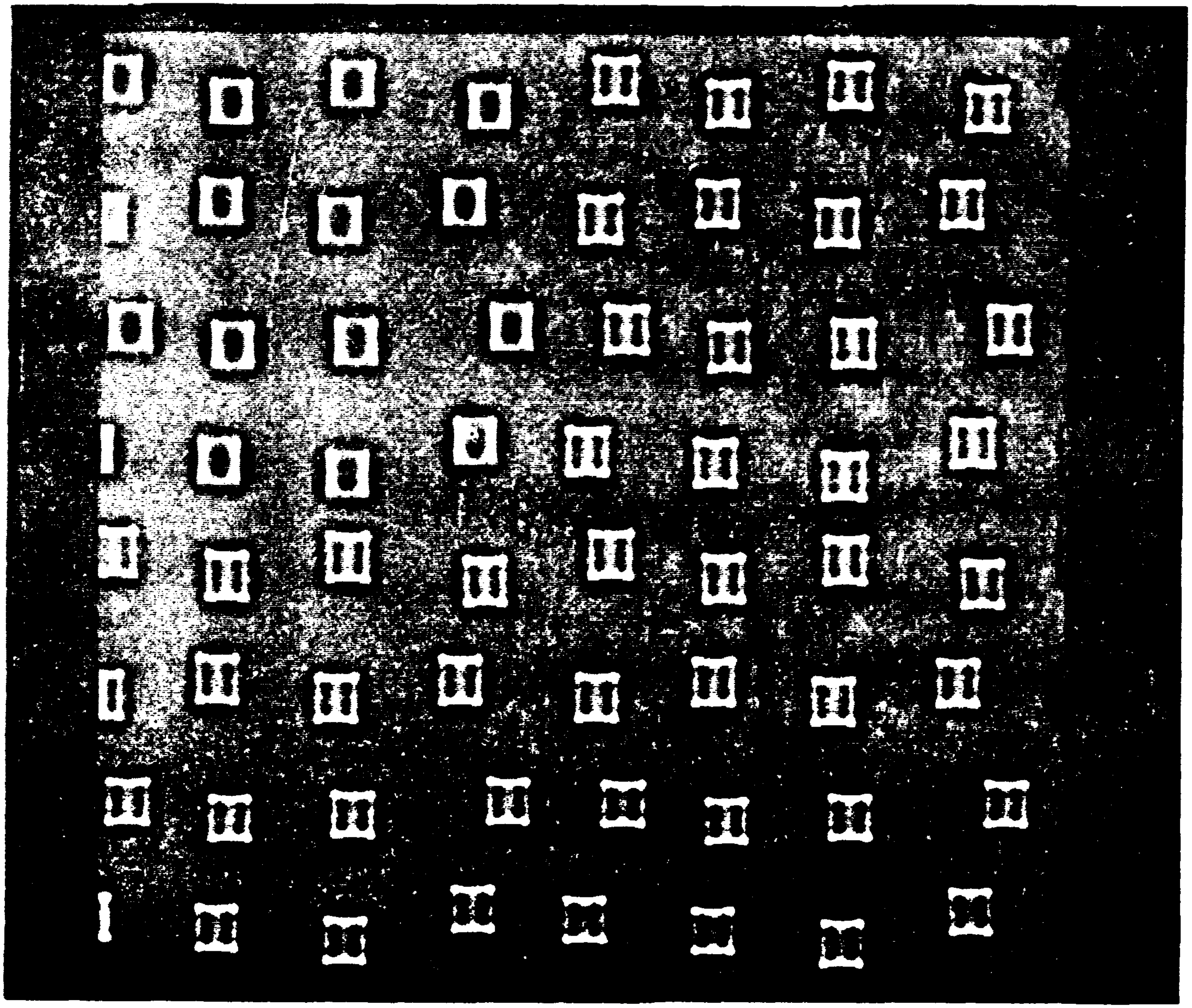


Figure 16

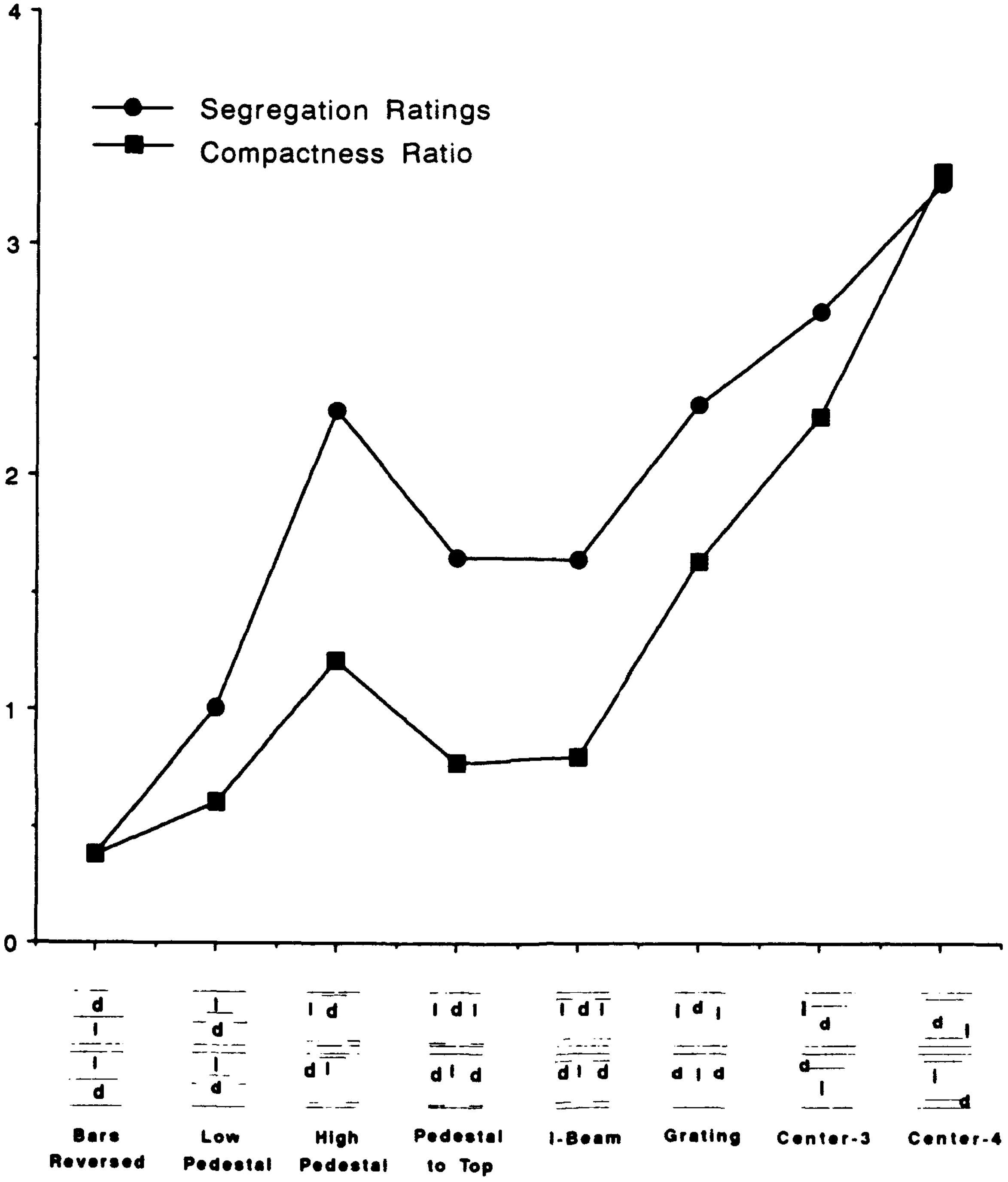

Segregation Ratings
Compactness Ratio
4
3
2
1
0
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4

Figure 17

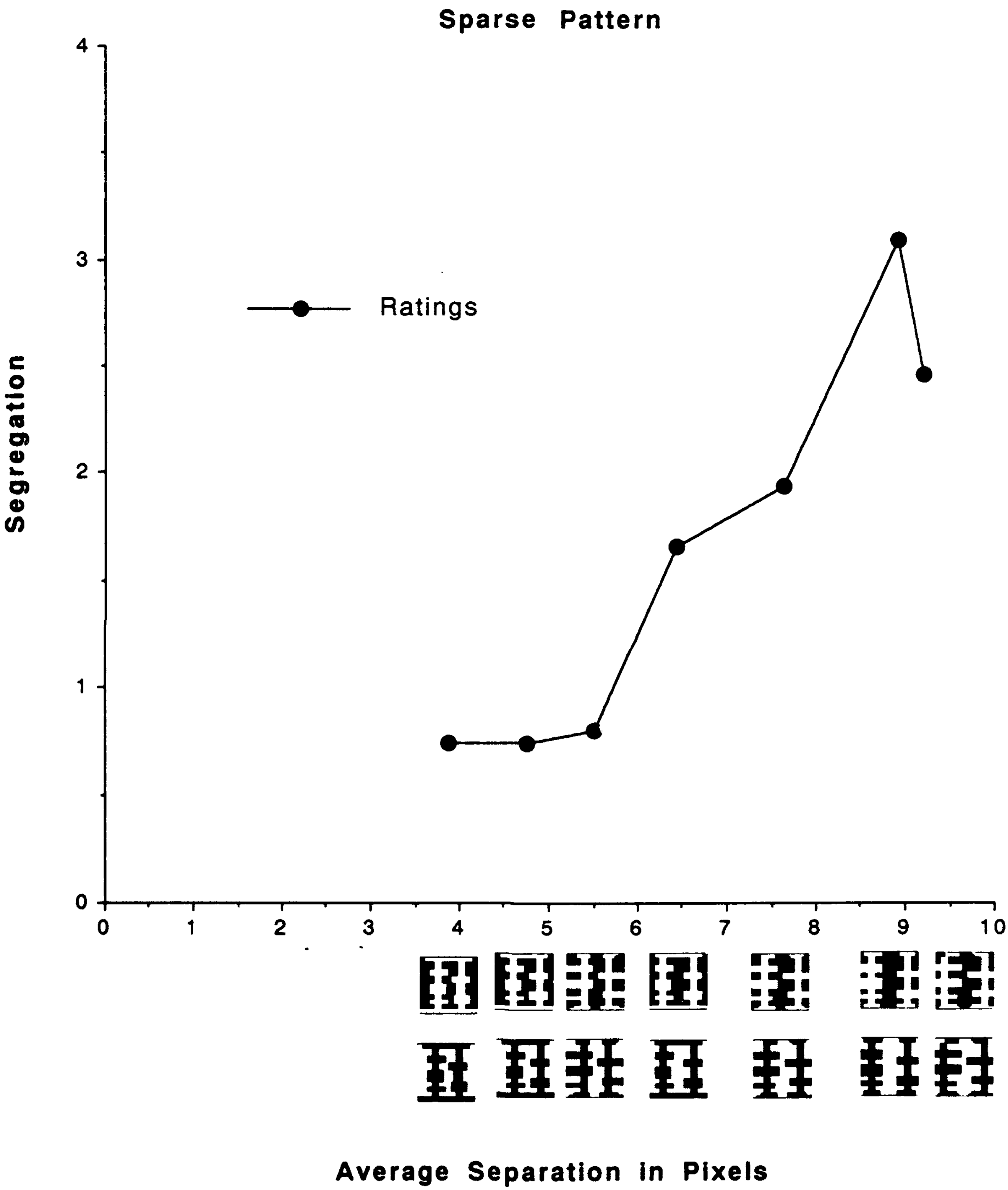

Sparse Pattern
Segregation
Ratings
0
1
2
3
4
0
1
2
3
4
5
6
7
8
9
10
Average Separation in Pixels

Figure 10

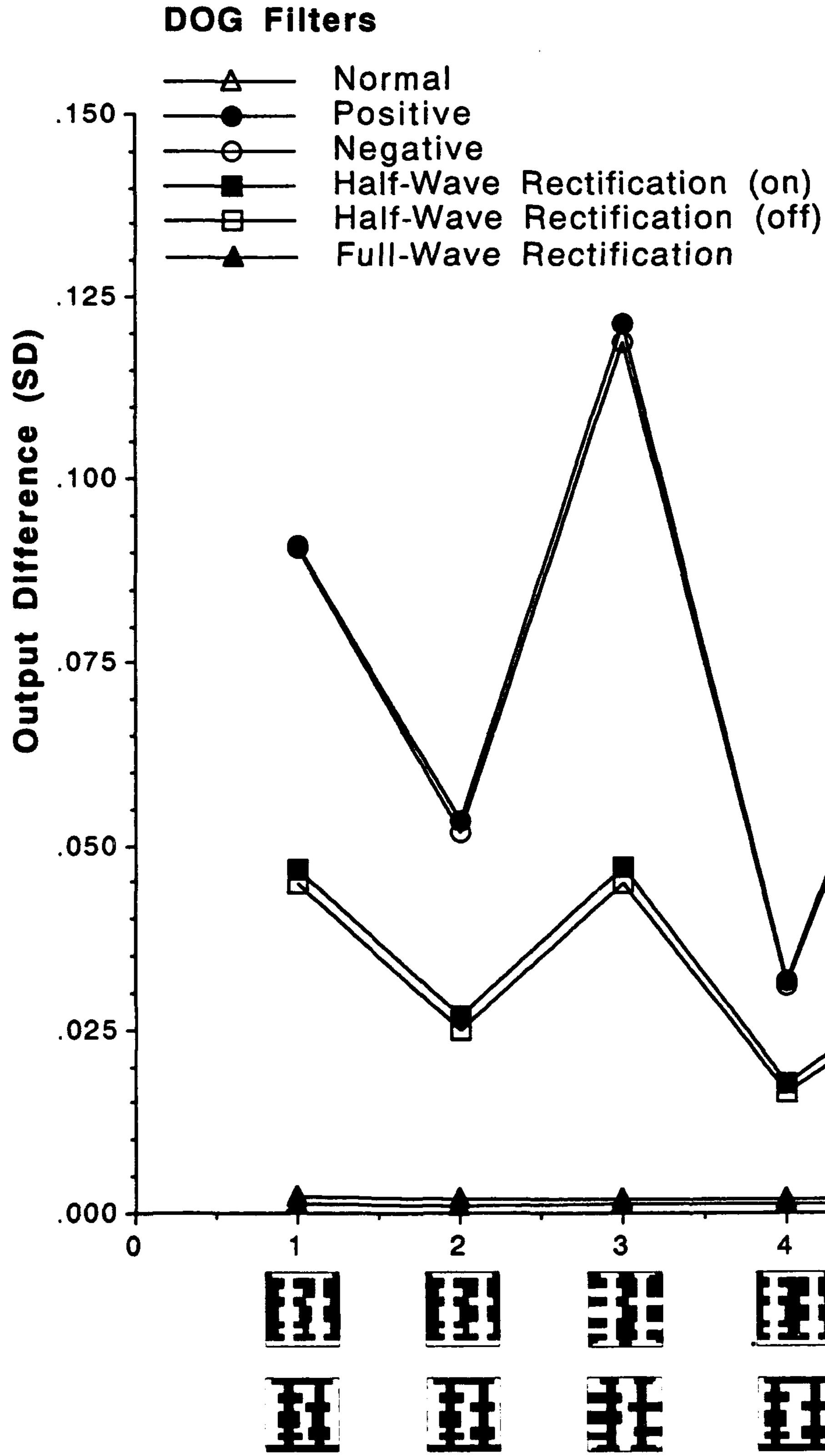

DOG Filters
Normal
Positive
Negative
Half-Wave Rectification (on)
Half-Wave Rectification (off)
Full-Wave Rectification
Output Difference (SD)
.150
.125
.100
.075
.050
.025
.000
0
1
2
3
4
5
6
7

Figure 19

20 shows that the outputs of the Gabor filters also fail to predict segregation. The results suggest that perceived segregation occurs when there is a single wide bar which is seen as light or dark. In contrast, segregation fails to occur when the vertical bars making up a pattern are roughly of equal width.

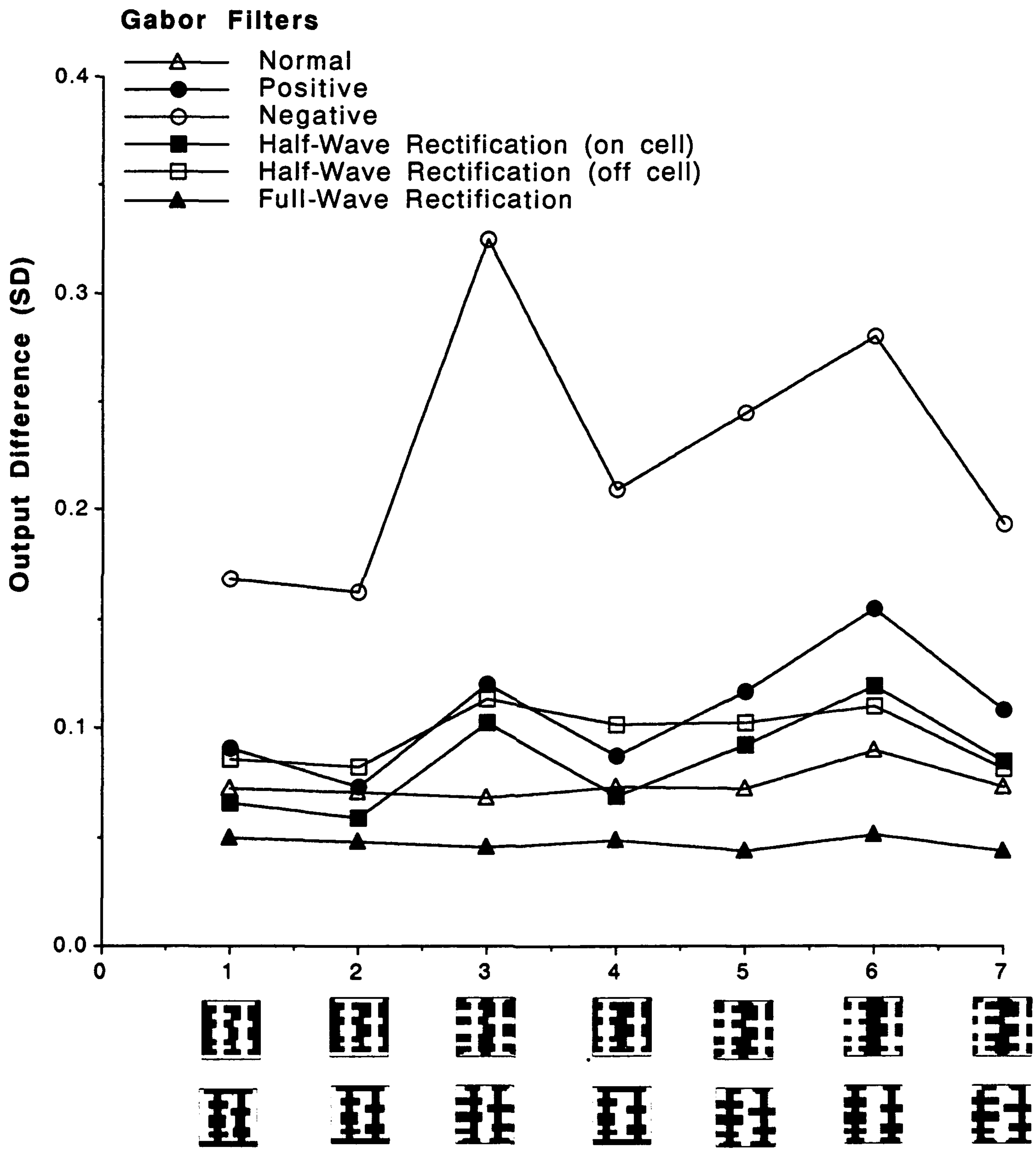
2.6 Bipartite Patterns

A second experiment also supports the view that the correspondences between the DOG and Type I filters and perceived segregation are accidental. The Center-4 (Figure 21) and I-Beam elements (Figure 22) were arranged in stripes and checks. Figure 23 shows that the subjects' ratings of perceived segregation are similar to the quadrants patterns. As mentioned previously, the element arrangement patterns respond primarily to the fundamental frequency of the pattern. Since the luminances of the two elements are the same and both elements are present in both regions, the DOG and Gabor filters should respond approximately the same in the striped and checked regions. Figure 24 shows that the outputs of the Gabor and DOG filters fail to correspond to the perceived segregation.

2.7 Discussion

The experiments reported indicate that perceived segregation is not explainable as a direct consequence of the differential stimulation of spatial frequency channels. Texture segregation can not be explained in terms of solely linear operations and the application of spatial frequency analysis to texture segregation involves nonlinearities. A scheme followed by many of the models, including the one proposed by Graham, Sutter, and myself, involve three processing stages: an initial filtering by localized linear filters, a nonlinear transformation, and a second refiltering by localized linear filters. There are many parameters in such a model and we have not been able to definitely reject this more complex model though I have not been able to see how to explain the experimental results using such a model.

Texture segregation produced by figural differences correspond to their discriminability when presented extrafoveally in a mutielement display in which a subject is uncertain about the position of the target and can not focus his or her attention (Beck, 1972; 1982). I called this kind of discriminability peripheral discriminability under uncertainty. For both the I-Beam and Center-4 patterns, and the irregular figures we found that the peripheral discriminability under uncertainty was greater for the elements yielding strong texture segregation than for the elements yielding weak texture segregation. This suggests that texture segregation is a function of the salience of a stimulus difference. Property differences such as difference in lightness and hue which are salient give strong preattentive texture segregation. In contrast, the change in figure-ground in the discrepant and non-discrepant quadrants of the I-Beam is not salient and does not yield strong perceived segregation. Salience is determined not only by the lightness difference but also by a large uniform area of color. Figure 25 shows that the Gabor filter outputs are similar for the I-Beam and Center-4 elements as a function of the luminance differences of the figure and surround in an element. The background was 28 ft.-L., the I-Beam and Center-4 figures 2 ft.-L., and the element surround varied from 6 to 15 ft.-L. Preliminary results of an ongoing experiments indicate that the perceived segregation of the I-Beam increases with the increased differences in filter outputs. In contrast, the perceived segregation of the Center-4 pattern is approximately 4 and does not vary with the filter outputs. What is suggested is that the segregation of the Center-4 pattern



Gabor Filters
Normal
Positive
Negative
Half-Wave Rectification (on cell)
Half-Wave Rectification (off cell)
Full-Wave Rectification
Output Difference (SD)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7

Figure 20

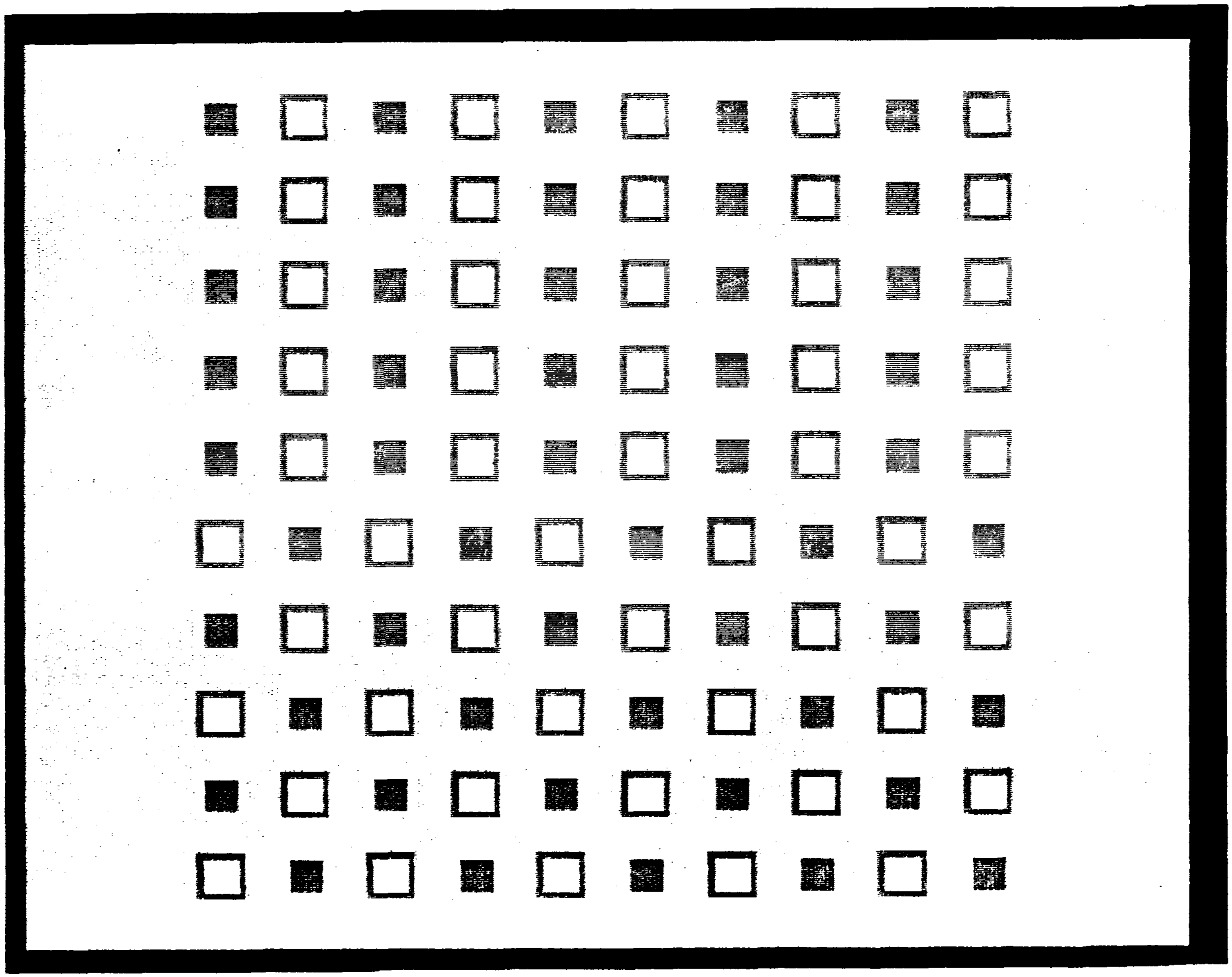


Figure 21

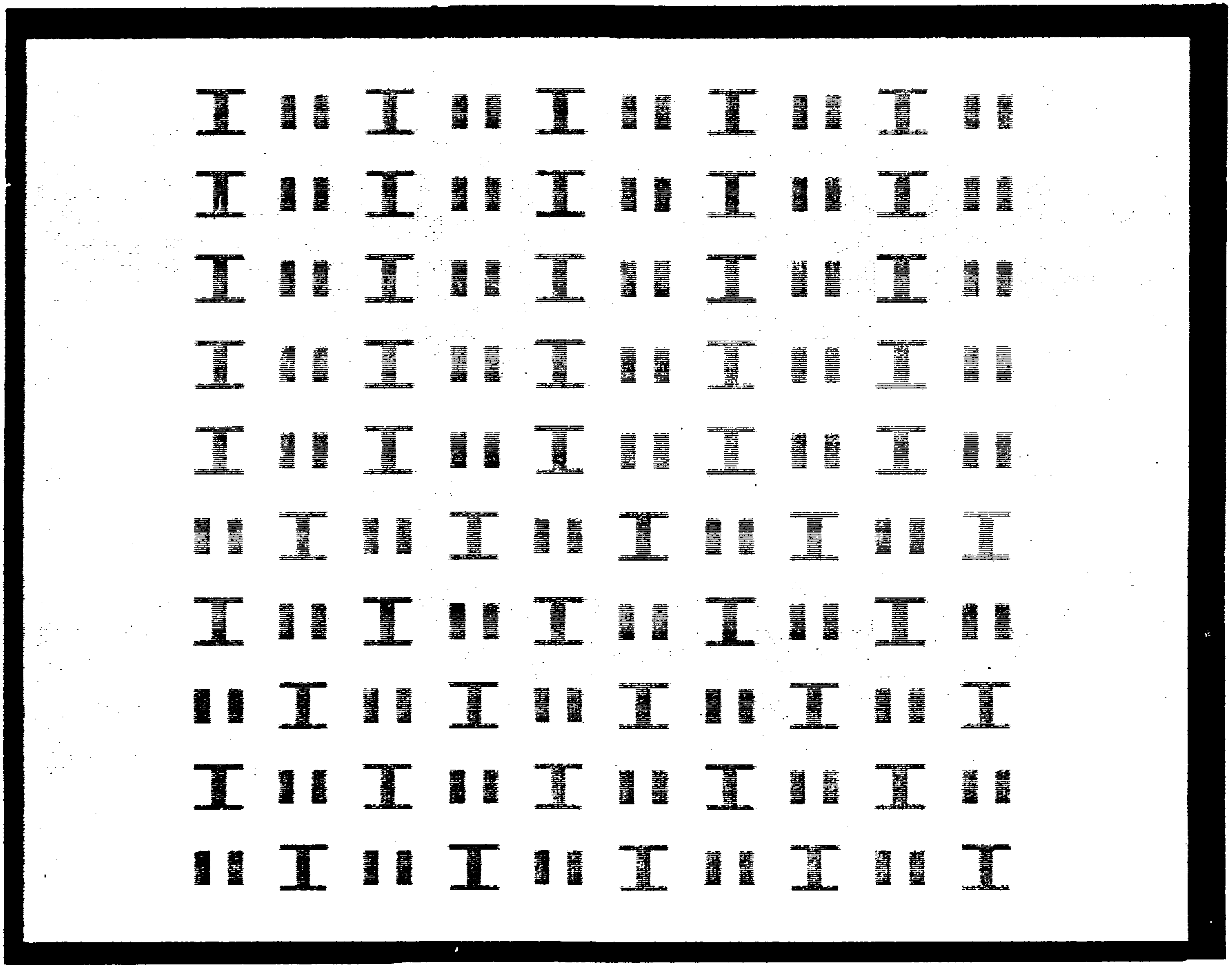


Figure 22

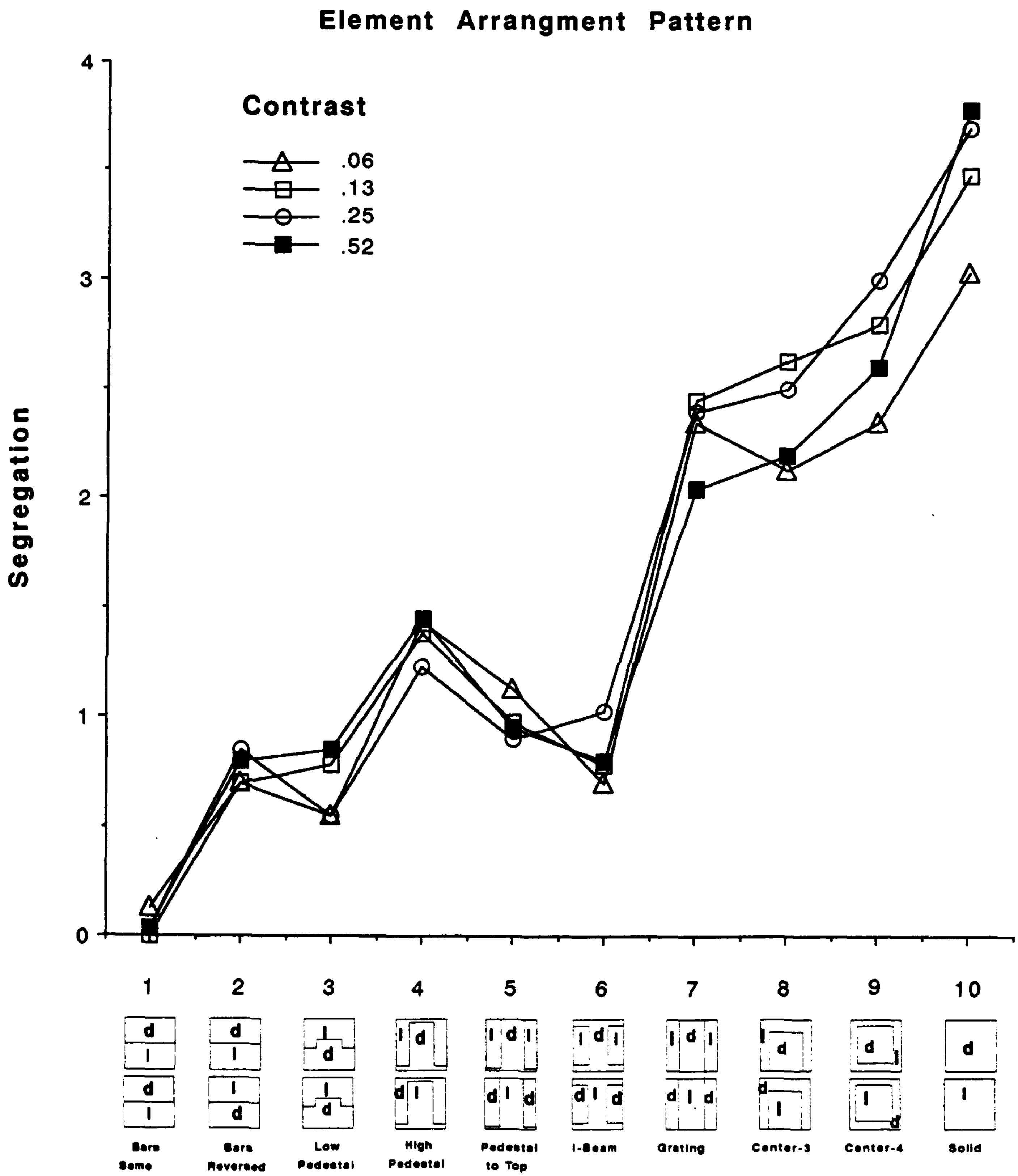
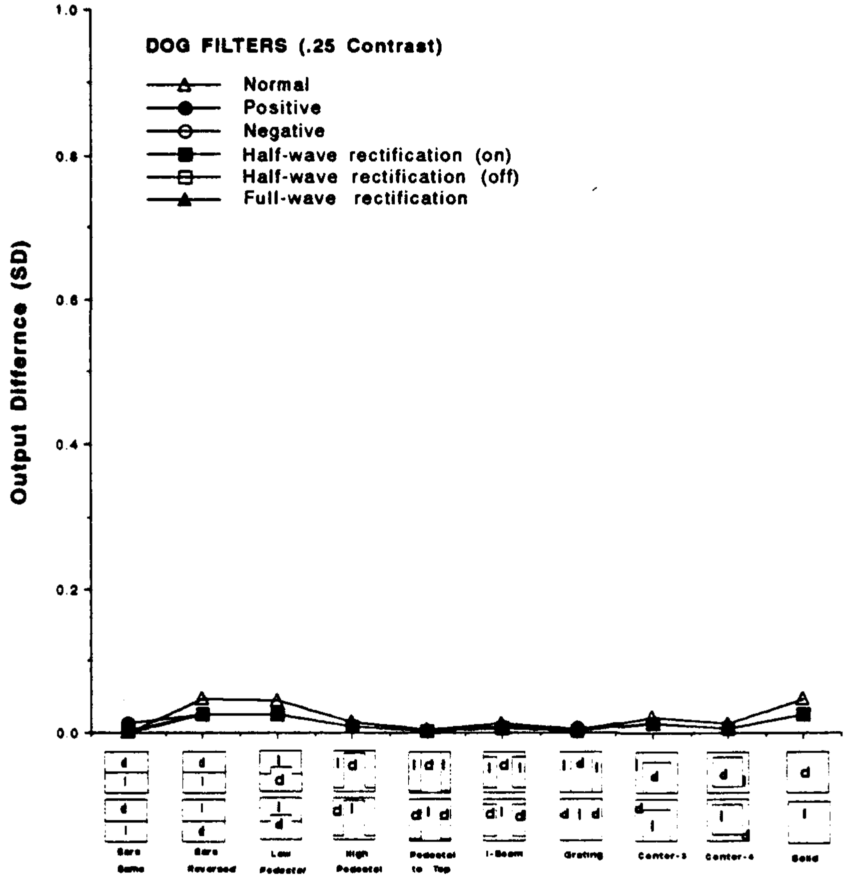

Element Arrangment Pattern
Contrast
.06
.13
.25
.52
Segregation
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
Bars Same
Bars Reversed
Low Pedestal
High Pedestal
Pedestal to Top
I-Beam
Grating
Center-3
Center-4
Solid

Figure 22

Element Arrangement Patterns



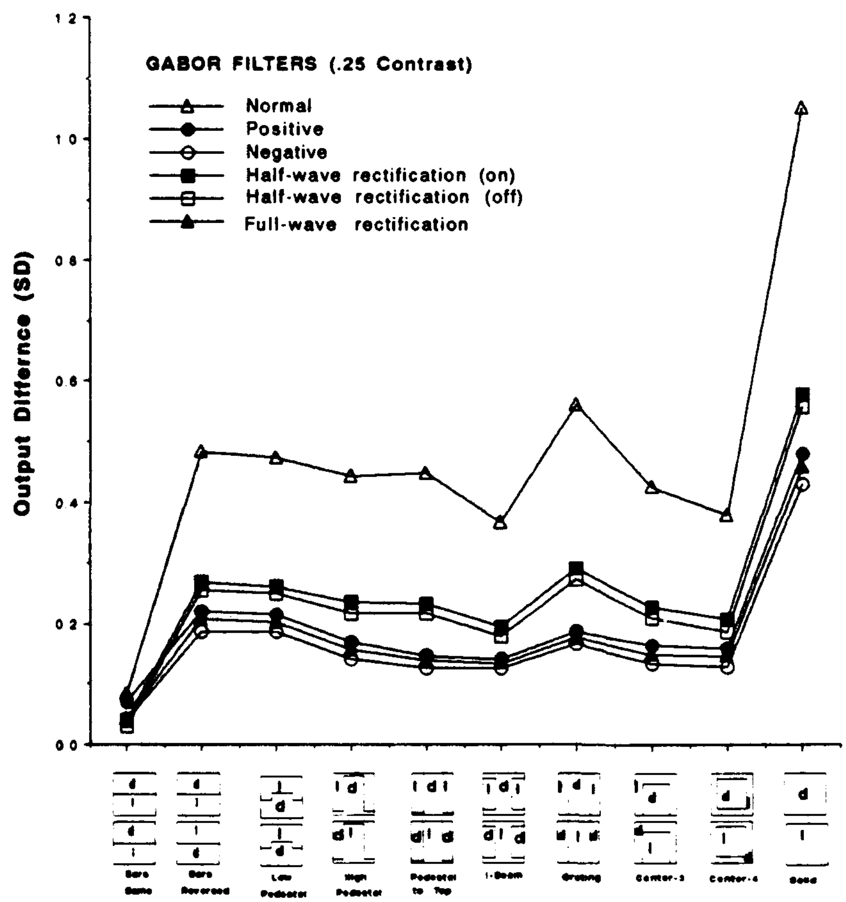


Figure 24

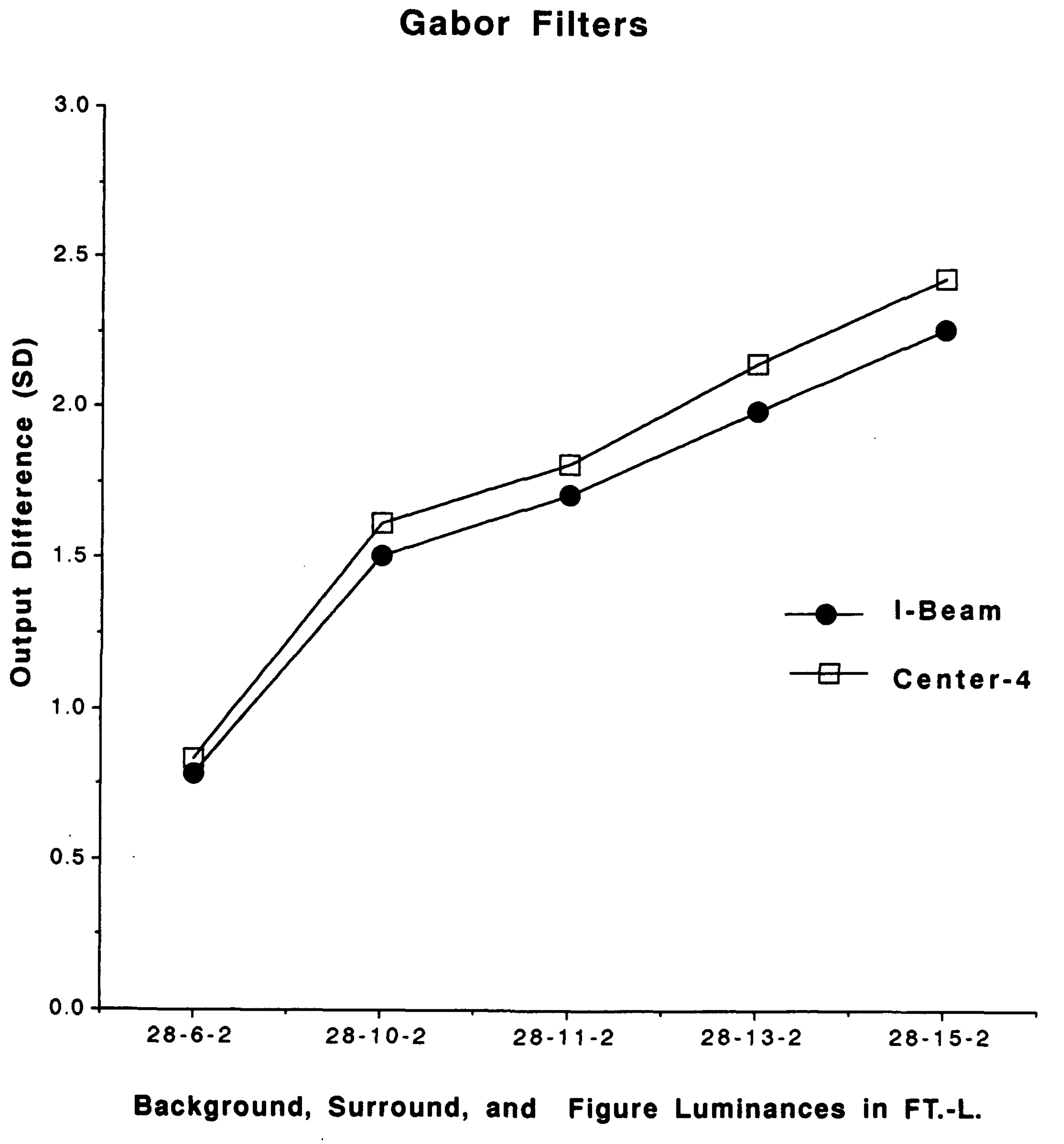

Gabor Filters
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Output Difference (SD)
I-Beam
Center-4
28-6-2
28-10-2
28-11-2
28-13-2
28-15-2
Background, Surround, and Figure Luminances in FT.-L.

Figure 25

is due to the salience of the lightness difference and that a large uniform area, the center square, increases the salience of this lightness difference.

2.8. Three-Dimensional Representation

We also investigated the properties of 2D and 3D perceived shapes yielding region and population segregation. Previous research with 2D perceived shapes found that differences in the spatial relations between features such as the arrangement of lines in a shape that leave the slopes of the component lines the same do not generally yield strong texture segregation (Beck, 1982). Enns (1990) showed that this generalization does not hold for visual search when the shapes appear three-dimensional. Parallel visual search was possible for targets and distractors equated for 2D features (eg. number and slopes of lines) that differed in their perceived 3D orientation. Ramachandran (1990) also found that convexity and concavity conveyed by gradients of shading yields grouping of a population into subpopulations. Similar lightness changes that did not look three-dimensional did not segregate.

2.9 Region and Population Segregation

The region stimuli were composed of four quadrants. The elements in one quadrant differed from those in other quadrants. The discrepant quadrant appeared equally often in each of the four corners. The population stimuli were composed of two interspersed subpopulations. Subjects rated the segregation of the discrepant quadrant and of the subpopulations on a scale from 0 to 4.

Chromatic and achromatic cube and circle stimuli were presented. The chromatic cube in the non-discrepant quadrants and in one subpopulation consisted of a top black, a left green, and a red right lozenge. The chromatic circle in the non-discrepant quadrants and in one subpopulation consisted of a top black, a green left, and a red right circle. The achromatic cubes and circles were black, gray, and white as shown in the top of Figure 26. The abscissa in Figure 26 identifies the four transformations of the cube and circle presented in the discrepant quadrant and in one of the subpopulations: (1) the circles and cubes in the discrepant quadrant were identical to the circles and cubes in the non-discrepant quadrants (Identical), (2) the left and right lozenges of the cubes and the left and right circles of the circle stimuli were interchanged in the discrepant quadrant (Left-Right interchange), (3) the top and left lozenges of the cubes and the top and left circles of the circle stimuli were interchanged in the discrepant quadrant (Top-Left interchange), (4) The cubes and circles were rotated 180 degrees in the discrepant quadrant (180• rotation). To anchor the upper end of the scale four patterns were presented that yielded strong segregation. The patterns consisted of red and white lozenges and ovals. The lozenges and the ovals in the discrepant quadrant were rotated 45 degrees counter clockwise from the horizontal; the lozenges and the ovals in the non-discrepant quadrants were horizontal.

Figure 26 presents the results for the chromatic and achromatic region stimuli (top), and for the chromatic and achromatic population stimuli (bottom). The pattern of results are similar. A three-way ANOVA revealed that the main effects of element shape and the type of transformation were significant ($p < .01$). The cube patterns segregated more strongly than the circle patterns, and the strongest perceived segregation occurred with a 180 degree rotation. The main effect of

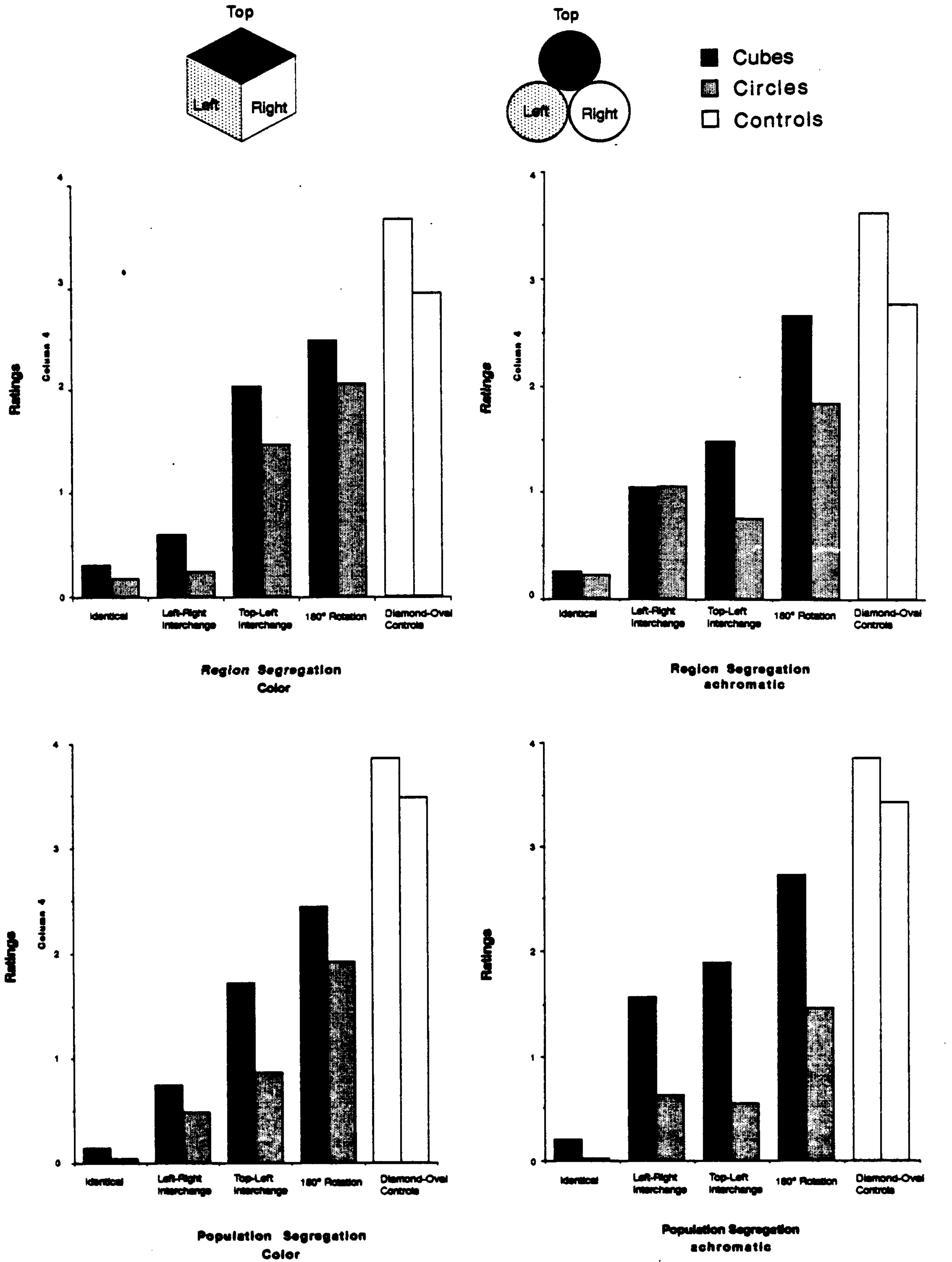

Top
Left
Right
Top
Left
Right
Cubes
Circles
Controls
Ratings
Column 4
Identical
Left-Right Interchange
Top-Left Interchange
180° Rotation
Diamond-Oval Controls
Region Segregation
Color
Region Segregation
achromatic
Population Segregation
Color
Population Segregation
achromatic

Figure 26

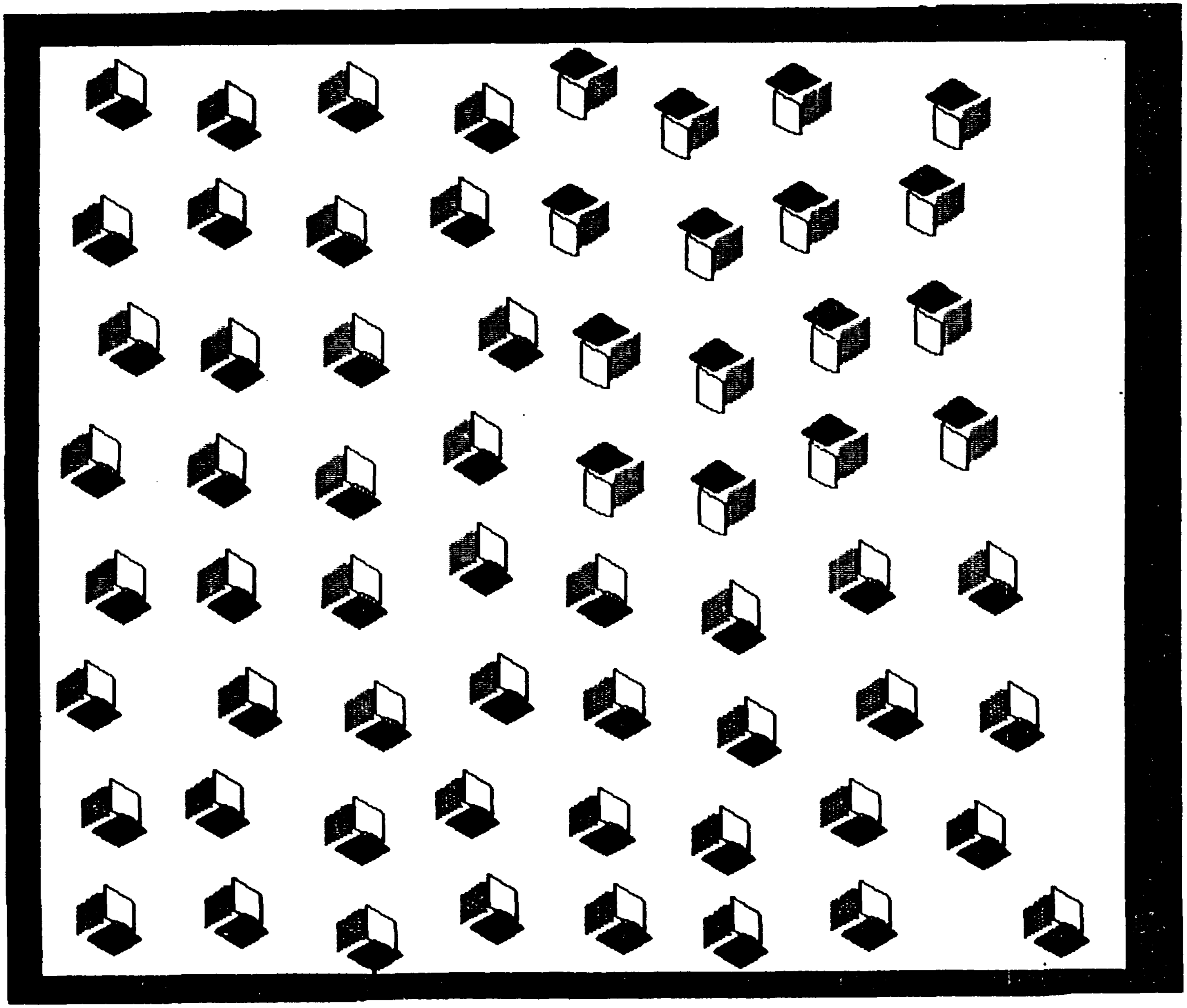


Figure 27

color was not significant. The segregation ratings of the chromatic and achromatic stimuli for both cubes and circles did not differ significantly.

As 2D patterns, the 180 degree rotations of the circle and cube stimuli differ only in the arrangement of their features and therefore should give similar segregation ratings. The generally greater segregation of the cube stimuli than of the circle stimuli suggest that segregation in these textures is not based only on the 2D features of the projected image but also on the 3D representation of the projected image. Why do changes in the arrangement of features which leave the orientations of the 2D projected lines the same yield stronger segregation with 3D than with 2D perceived figures? We do not know, but hypothesize that the differences are the result of grouping processes. For example, the arrangement of the lozenges in the top right quadrant of Figure 27 differs from that in the other quadrants. When seen as a 2D pattern the disparate quadrant does not segregate strongly. Proximity grouping of the white, gray, and black lozenges occurs. Similarity grouping of the lozenges by lightness, however, also occurs and interferes with the segregation of the discrepant quadrant. As a 2D pattern, the slants of the lozenges in perceptual space are the same, i.e. they are in the frontal plane. Pointing of shapes up and down in 2D space is not generally salient and requires focussed attention (Beck, 1972, 1982). When the lozenges are seen as the sides of a box in 3D space, the slants of the lozenges differ. It is possible that this both makes the pointing of objects in 3D space more salient and reduces the tendency to group lozenges of similar lightness across figures. As a consequence, the discrepant quadrant segregates. What is suggested is that the increased segregation is due to the introduction of new grouping processes. A 3D representation makes explicit the orientations of object surfaces enabling the grouping of objects by the similarity of their surface orientations, e.g., the directions of their surface normals.

2.10 Discussion

Effortless texture segregation requires parallel or rapid processing across the visual field and fails to occur if discrimination requires focussed attention to examine the elements in a display serially (1982). It can be quite difficult to unambiguously determine whether the processing of stimulus information is parallel or serial (Townsend, 1971; 1972). What is important for texture segregation is not strict parallel processing but whether stimulus properties can be processed quickly from different spatial locations. Beck and Ambler (1972; 1973) argued that texture segregation occurs for stimulus properties that are processed in parallel or if serially very quickly. Texture segregation does not occur if discrimination requires focussed attention and the one-by-one examination of stimulus figures.

Two types of texture segregation occurs. Texture segregation based on differences in the modulation of channel outputs and the 2D grouping of contour, lightness, and other simple properties can occur with preattentive or fully distributed attention. A second type of texture segregation depends on attention. Segregation based on the orientation of 3D surfaces depends on shape information. Observations suggest that segregation based on shape requires attentional processing. For example, the discrimination of convex and concave based on shading gradients take several seconds and appears to require focussed attention (Ramachandran, 1990). Attention acts to trigger texture segregation. Attention is required to see a given figure as three-dimensional. As soon as a figure is seen as three dimensional, the 3D interpretation is propagated in parallel or rapidly to the other figures in the pattern. A necessary condition for texture segregation is the rapid processing of stimulus differences. Texture segregation does not occur if discrimination of the relevant stimulus difference requires sequential attentional processing.

2.11 Conclusions

Preattentive texture segregation can occur in three ways. Texture segregation has been shown to occur as a result of differences in the outputs of local linear detectors that operate on intensity values and as a result of the grouping of discrete elements through edge alignment and lightness similarity.

The outputs of spatial-frequency channels with weighting functions like those simple cells (Gabor filters) can account for much of the segregation of visual displays into regions (Bergen & Landy in press). Texture segregation can not be explained in terms of solely linear operations, and the application of spatial-frequency analysis to texture segregation involves nonlinearities. Two nonlinearities have been shown to occur. One nonlinearity is an intensity dependent nonlinearity which can be accounted for by sensory adaptation occurring before the channels or by a compressive intracortical interaction among the channels. The second nonlinearity is a rectification-like nonlinearity similar to that presumed to occur in complex cells.

Texture segregation resulting from the alignment of element edges into a line-like pattern and the segregation of randomly interspersed populations of light and dark elements into subpopulations is not explainable as a direct consequence of the differential stimulation of spatial-frequency channels. The length of the line-like pattern is an "emergent" feature segregating it from the surrounding elements. Similarly, the grouping of intermixed light and dark squares through lightness similarity into subpopulations is an example of pure similarity grouping. Spatial-frequency channels and preattentive grouping processes may be distinguished by how they are affected by stimulus variables. An approximate area x contrast tradeoff occurs when texture segregation is a direct consequence of the way in which intensities in a texture pattern stimulate spatial-frequency channels, but not when texture segregation is a consequence of element edge alignment and element similarity. Also, the relevant variable for spatial-frequency channels is stimulus contrast whereas the relevant variable for similarity grouping is perceived lightness. Preattentive texture segregation occurs in terms of stimulus differences rather tan in terms of stimulus similarity. Wertheimer (1923) proposed that similarity grouping is and associative process based upon stimulus similarities. Similarity grouping , however, may also be described as a segregative process based upon stimulus differences. Beck (1982) proposed that preattentive texture segregation depended on stimulus differences.

Texture segregation may also be affected by the stimulus representation. Changes in the orientation of a stimulus which keeps the slopes of the component features constant yields stronger texture segregation when the figures were seen as three-dimensional than when the figures were seen as two-dimensional. The greater texture segregation with a 3D representation is hypothesized to be a consequence of grouping processes. A 3D representation makes evident the orientation of object surfaces enabling the grouping of objects by the similarity of their surface orientations, e.g., the directions of their surface normals. The normals to a 2D figures are perpendicular to the picture plane. The normals to the surfaces of 3D objects vary in orientation. Unlike grouping based on edge alignment and lightness similarity, grouping based on the interpretation of projected shapes appears to require a focussing of attention. Attention appears necessary for generating a three-dimensional interpretation. Texture segregation occurs when a three-dimensional interpretation is propagated rapidly through a pattern and does not depend on attentional processing.

3. REFERENCES

Beck, J. (1972). Similarity grouping and peripheral discriminability under uncertainty. *American Journal of Psychology*, **85**, 1-19.

Beck, J. (1973). Similarity grouping of curves. *Perceptual and Motor Skills*, **36**, 1331-1341.

Beck, J. (1982). Textural segmentation. In: *Organization and Representation in Perception*, J. Beck (Ed.) Erlbaum, Hillsdale, N.J. (pp. 285-317).

Beck J., (in press) Visual processing in texture segregation. *Proceedings of the second international conference on visual search*, D. Brogan (Ed.) London: Taylor & Francis

Beck, J. & Ambler, B. (1972). Discriminability of differences in line slope and in line arrangement as a function of mask delay. *Perception and Psychophysics*, **12**, 33-38.

Beck, J. & Ambler, B. (1973). The effects of concentrated and distributed attention on peripheral acuity. *Perception and Psychophysics*, **14**, 225-230.

Beck, J., Prazdny, K., & Rosenfeld, A. (1983). A theory of textural segmentation. In: *Human and Machine Vision*, J. Beck, B. Hope, & A.Rosenfeld, (Eds.). New York: Academic Press (pp.1-38).

Beck, J., Sutter, A. & Ivry, R. (1987). Spatial frequency channels and perceptual grouping in texture segregation. *Computer Vision, Graphics, and Image Processing*, **37**, 299-325.

Beck, J., Rosenfeld, A. & Ivry, R. (1989). Line segregation. *Spatial Vision*, **4**, 75-101.

Beck, J., Graham, N. & Sutter, A. (1990). The effects of lightness differences on the perceived segregation of regions and populations *Perception and Psychophysics*, **49**, 257-269.

Bergen, J. R. & Landy, M.S. (in press). Computational modeling of visual texture segregation. In *Computational Models of Visual Processing*, M.S. Landy & J. A. Movshon, (Eds.). Cambridge, MA: MIT Press.

Enns, J. T. (1988). Three dimensional features that pop out in visual search. *First International Conference on Visual Search*, Durham, U.K.

Graham, N., Beck, J. & Sutter, A. (1989). Two nonlinearities in texture segregation. *Supplement to Investigative Ophthalmology and Visual Science*, **30**, 361.

Graham, N., Beck, J. & Sutter, A. (in press) Nonlinear processes in spatial-frequency channel models of perceived texture segregation: effects of sign and amount of contrast, *Vision Research*.

Grossberg, S. & Mingolla, E. (1985). Neural dynamics of perceptual grouping: textures, boundaries, and emergent features. *Perception & Psychophysics*, **38**, 141-171.

Ramachandran, V. S. (1990). Perception of depth from shading. *Scientific American*, **269**, 76-83.

Spitzer, H., & Hochstein, S. (1988). Complex-cell receptive field models. *Progress in Neurobiology*, **31**, 285-309.

Sutter, A., Beck, J., & Graham, N. (1989). Contrast and spatial variables in texture segregation: testing a simple spatial frequency channels model. *Perception & Psychophysics*, **46**, 312-332.

Townsend, J.T. (1971) A note on the identifiability of parallel and serial processes. *Perception and Psychophysics*, **10**, 161-163.

Townsend, J.T. (1972) Some results on the identifability of parallel and serial processes. *British Journal of Mathematical and Statistical Psychoogy*, **25, 168-199.**

Ts'o D.Y. & Gilbert, C.D. (1988). The organization of chromatic and spatial interactions in the primate striate cortex. *The Journal of Neuroscience*, **8**, 1712-1727.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt, II. *Psychologische Forschung*, **4**, 301-350.

4. PUBLICATIONS (reporting AFOSR research, 1988-1991)

Graham, N. (1989). Low-level visual processes and texture segregation. *Physica Scripta*, **39**, 147-152.

Sutter, A., Beck, J., & Graham, N. (1989). Contrast and spatial variables in texture segregation: testing a simple spatial-frequency channels model. *Perception & Psychophysics*, **46**, 312-332.

Sutter, A., Beck, J. & Graham, N. (1989). Contrast and spatial variables in texture segregation: testing a simple spatial-frequency channels model. *Perception and Psychophysics*, **46**, 312-332.

Beck, J., Rosenfeld, A. & Ivry, R. (1989). Line segregation. *Spatial Vision*, **4**, 75-101.

Beck, J., Graham, N., & Sutter, A. (1991). Lightness differences and the perceived segregation of regions and populations. *Perception and Psychophysics*, **49**, 257-269.

Graham, N., Beck, J. & Sutter, A. (in press) Nonlinear processes in spatial-frequency channel models of perceived texture segregation: effects of sign and amount of contrast, *Vision Research*.

Beck J., Visual processing in texture segregation. (in press) *Proceedings of the second international conference on visual search*, D. Brogan (Ed.) London: Taylor & Francis.

Beck J., & Goodwin, W., Prevailing color and texture segregation. In preparation.

5. MEETINGS (reporting AFOSR research, 1988-1991)

Twenty-ninth Annual Meeting of the Psychonomic Society, Chicago, Illinois, 1988, "Texture segmentation."

Fifth Human and Machine Vision Workshop, North Falmouth, Massachusetts, 1989, "Line segregation."

Twelfth European Conference on Visual Perception, Zichron Yaakov, Israel, 1989, "Two cases of preattentive segregation."

Thirty-first Annual Meeting of the Psychonomic Society, New Orleans, Louisiana, 1990, "Lightness differences and the perceived segregation of regins and populations."

Second International Conference on Visual Search, Durham, England, 1990, The British Aerospace Lecture "Effortless visual segregation: stimuli, processes, and representations."

Neural Networks for Vision and Image Processing, Tyngsboro, Massachusetts, 1991, "Visual processing in texture segregation."

Thirty-second Annual Meeting of the Psychonomic Society, San Francisco, California, 1991, "Prevailing lightness and texture segregation."

Colloquia were presented at Boston University (1990) and the University of California, San Diego (1991)

6. PROFESSIONAL PERSONNEL

Principal Investigator: Jacob Beck

Visiting Graduate Fellow (Madrid, Spain): Diana Perez

Programmer: Will Goodwin

Graduate Student: John Bainbridge

Undergraduate students: Randy Hammond, Robert Graden

END

FILMED

DATE: 3-92

DTIC