Assimilation and Contrast

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Abstract

In complex scenes the same gray material appears the same in different places in the scene. In simple displays, grays vary in lightness with surround. By definition "contrast" is the name of the mechanism that makes grays look darker in a white surround than in a black surround. It is generally believed that the white surround stimulates inhibition of the center, making that gray look darker. The black surround does not generate inhibition and hence the gray appears lighter.

Assimilation is the name of the mechanism with the opposite effect. Grays with adjacent white no longer look darker than the same gray with adjacent black. Examples are Benary's Cross, White's Effect, Checkerboard and Dungeon Illusions. These effects have been used to suggest a top-down analysis of the scene, implying mechanisms based on the recognition of illumination, objects or junctions.

Recent experiments demonstrate that contrast is much more complex than inhibition by average luminance in the surround. Displays with a square, gray central element and 8 square surround elements demonstrate significant sensitivity to the placement of white and black surround elements. Equal-average surrounds do not give equal gray appearances. Other experiments show that periodic assimilation effects are sensitive to average luminance over very-large-receptive fields. All of the above assimilation effects have gray center lightnesses that correlate with large-receptive-field averages. Contrast is the result of complex spatial interactions, while assimilation is due to large receptive field averages. Experiments studying the transition from contrast to assimilation are described.

Introduction

In real scenes and in complex Mondrians the appearance of two identical colored papers in different locations is remarkably constant. Changing the position, and hence the surround, does not usually alter appearance. In simple displays, grays vary in lightness with surround. Depending on the spatial arrangement of the surround it can make appearance more similar to the surround (assimilation), or more different (contrast) from the surround. Models that convert real image radiances to calculated sensations[1] exhibit contrast, but not assimilation. In order to expand the model to also exhibit assimilation, it is necessary to process the image in parallel, keeping separate the outputs of different spatial frequency channels.[2] This paper studies the visual affects of segmented surrounds to understand the transition from contrast to assimilation.

In describing lightness effects "contrast" is the mechanism responsible for the fact that a white surround makes a gray center appear darker than a black surround. Following Barlow's[3] and Kuffler's[4] discovery of spatial opponent ganglion cells, it is generally believed that the white surround stimulates inhibition of the center, making that gray look darker. The black surround does not generate inhibition and that gray appears lighter. It is important to recall that these displays are usually much larger than the receptive fields of ganglion cells.

Assimilation is the name of the mechanism with the opposite effect.[5] Grays with adjacent white no longer look darker than the same gray with adjacent black. Examples are Benary's Cross, White's Effect, Checkerboard and Dungeon Illusions. These effects have been used to suggest a top-down analysis of the scene, implying mechanisms based on the recognition of illumination, objects or junctions.

Recent experiments demonstrate that contrast is much more complex than inhibition by average luminance in the surround.[6] Contrast is the result of complex spatial interactions, while assimilation can be understood as large receptive field averages.[7] One cannot assume that assimilation experiments are evidence for unconscious inference.

Segmented Surrounds

This paper reports experiments using segmented black and white surrounds. Figure 1 illustrates a "1346" test target.

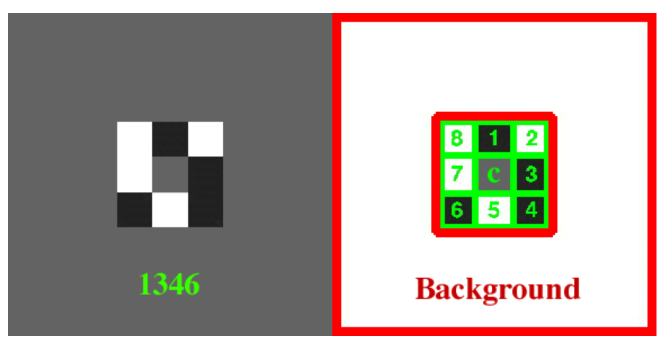


Figure 1 shows a "1346" segmented test target (left) and a diagram of the nomenclature (right). The center [c] and the constant background was fixed at 17% maximum luminance. The surround was segmented into 8 elements, numbered clockwise starting at the top center. Independently, the luminance of each of eight surround segments could be set to 100% or 3%. This display has 3% luminance in the 1,3,4,6 segments, hence its name.

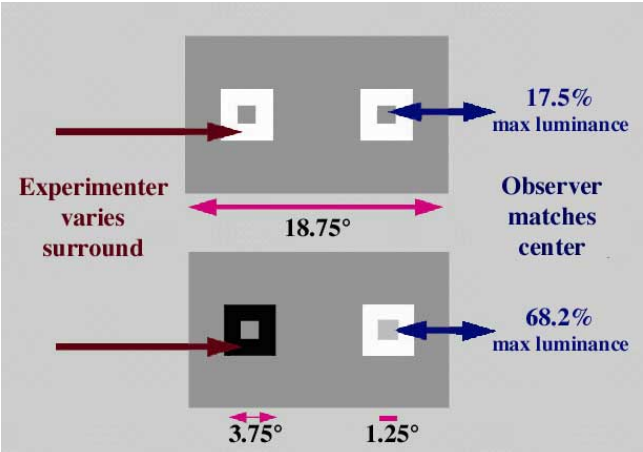


Figure 2 diagrams the segmented surround experiment. In a dimly lit room, observers viewed an 18.75° by 11.25° background. On the left observers saw a variable 3.75° test surround and a 1.25° test center. On the right observers saw a constant 3.75° maximum-luminance [100%] surround and an observer-controlled, variable intensity, 1.25°-matching center. The experimenter controlled the pattern of the segmented surround on the left. The observer varied the intensity of the right gray center in a constant maximum luminance surround. With all eight 100% surround elements the observers matched 17% maximum luminance; with all 3% surround elements the observers matched 66% maximum luminance.

The square gray center element subtends 1.25° with 8 surrounding elements (4 adjacent- 4 diagonal). There are 256 combinations of white and black elements in 8 locations. A single black segment at position the top centerposition 1 [north] is assumed to be the same as all the other single adjacent black squares 3 [east], 5 [south], and 7 [west]. Target 1 was tested and the stereoisomers, targets 3,5 and 7 were not. Removing all the stereoisomers leaves 56 unique spatial surround tests.

The 3x3 segment test target and the same size white-surround matching display were both on 18.75° x 11.25° gray background (Figure 2). With 8-white-surround elements, grays matched 17.5% maximum luminance [17.9%± 2.5% MAM/ 17.3%±0.4% JMC]; with 8-black-surround, 68.2 % maximum luminance [67.9% ± 6.52% MAM/ 68.5± 6.52% JMC]. The results are analyzed using log luminance axes with 100% scaled to 1.0. The matching value on this scale for white surround is 0.23, and for the black surround is 0.85.

The result from all 56 targets, for 8 trials each target, for two observers is shown in Figure 3. The vertical axis is the average log matching luminance (LML). The horizontal axis identifies the segmented surround. The data has been sorted so that the number of black elements increases from left to right. The matches showed little correlation with number of black segments, or spatial average. If the number of black elements, or a surround average, were controlling contrast, then we might expect a series of flat steps with vertical risers at the

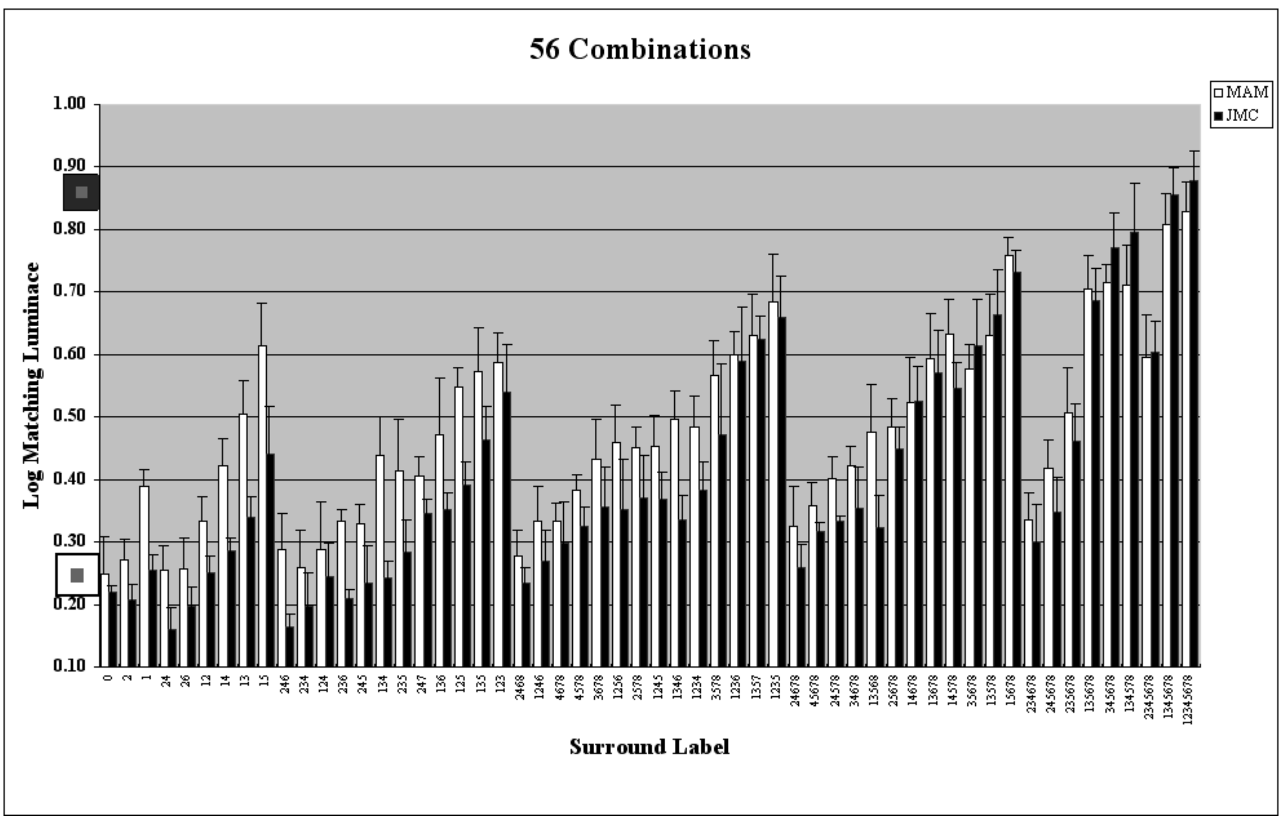


Figure 3 shows matching data for the all 56 surround targets. The horizontal axis identifies the segmented surround using the nomenclaure described above. The vertical axis plots the observer match, logarithmically scaled. The all-white and all-black surround icons identify the range of observer matches with uniform surrounds. If average luminace in the surround controlled the match, we would expect a staircase plot with constant number of black steps having constant matching luminace. Surrounds with a constant number of black segments have many different matching luminances. Matches vary depending on the placement of the white and black surround elements.

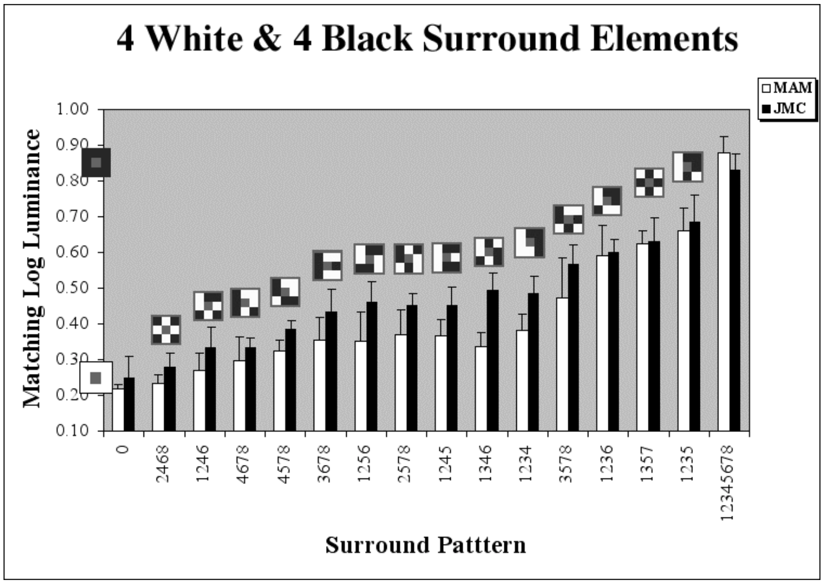


Figure 4 shows matching data for the all the 4-white/4-black surround targets. All 14 targets have the same average surround luminance. The horizontal axis identifies the segmented surround (illustrations above the bars). The vertical axis plots the observer match logarithmically scaled. The matching data is inconsistent with the hypothesis that appearance is controlled by the average luminance of the surround. Matches vary from 0.26 to 0.63 depending on the arrangement of the white and black surround elements.

change in number of black segments. Instead we found a marked dependence on the surround's spatial pattern. Target 2 (LML=0.24) with one diagonal black segment is the same as target 0 (LML=0.23) with an all white surround. However, target 1 with one adjacent black segment is lighter (LML=0.32). Among the 6 targets with two black sectors, the average log matching luminances vary from 0.22 to 0.53. Among the 12 targets with three black sectors, the average log matching luminances vary from 0.26 to 0.56. Among the 14 targets with four black sectors, the average log matching luminances vary from 0.26 to 0.67. Among the 12 targets with five black sectors, the average log matching luminances vary from 0.29 to 0.74. Among the 6 targets with six black sectors, the average log matching luminances vary from 0.31 to 0.75. In the 2 targets with two black sectors, the average log matching luminances vary from 0.22 to 0.53. Target 2345678 (LML=0.83) with one diagonal white segment is the same as the all black target 12345678 (LML=0.85). However, target 2345678 with one adjacent white segment is darker (LML=0.59). Instead of flat steps, correlating with number of black sectors, we find that there is a very wide range of matches for each set of constant number of black sectors.

Figure 4 is a plot of Segment Pattern vs. Log Matching Luminance for all 14 patterns with 4 white and 4 black elements in the surround. They are sorted from left to right in order of increasing average log matching luminance. The two lowest LML values have 0 adjacent blacks. The next two patterns have one adjacent black. The next 7 LML values have two adjacent blacks. The remaining five LML values increase with the number of adjacent blacks, but with more variability than previous patterns. The adjacent segment has more influence than the diagonal on matching luminance. The data from the 14 test targets with 4 white and 4 black elements is more consistent with the number of gray-black edges / gray-white edges than with the average luminance of the surround. The number of black segments is not a sufficient explanation of this data. A more complex spatial analysis is required.

It is important to note that although the data is reported in terms of number of gray-black segments, it is equally accurate to describe it as the number of gray-white edges. The essential result here is that the spatial pattern, and not the average of the spatial pattern, correlates with matching luminance. The mechanism controlling the appearance of the grays is not identified further by these experiments. Other experiments studying assimilation make that point very well.

The analysis of data from all 56 test targets shows that adjacent elements have much more influence than diagonal elements, although adjacent elements alone cannot account for the matching data. The appearance of grays with segmented surrounds having constant average luminance show dependence on spatial pattern. Contrast effects with segmented surrounds are much more complex than center and averaged-surround opponent processes.

Assimilation

Although often associated with top-down cognitive interpretations, Benary's Cross, White's Effect, the Checkerboard and Dungeon Illusions can be explained by spatial averaging. All four of these experiments demonstrate appearance shifts opposite to those found in simultaneous contrast. Here, grays with adjacent white no longer look darker than those surrounded by black. Unlike the above segmented contrast effects, these experiments show a correlation of appearance with spatial averages.[7]

Figure 5 shows the results of using a large gaussian filter to simulate receptive pooling of the input stimulus. The left column shows the original effects. The right shows the gaussian average. This process mimics the effect of very large receptive field responses. The areas corresponding to the gray test areas are pasted below with the average value. In each case, the average value of the receptor pools correspond to the apparent lightness of the gray test areas.

Figure 5 shows a gaussian shaped integration filter calculates a pixel-by-pixel coarse spatial average of the original image. The input image has 448 by 320 pixels. It is sampled in a 128 by 128 pixel window. The pixel intensities in the input window are multiplied by the gaussian spatial filter with sigma =16 and size = 128(middle). The normalized sum of all pixels in the window is the output for the pixel in the center of the window. The process is repeated for input pixels that are more than 63 pixels from the outer perimeter, forming a 320 by 192 pixel array. The second row shows Benary's Cross input image on the left. The right shows the gaussian filtered image. The output values for the equal-input gray areas are shown below. The average intensities for the darker gray triangle is 98, and for the lighter triangle is 119. The third row shows White's Effect input image; the right shows the gaussian filtered image. The average intensities for the darker gray bars is 106, and for the lighter bars is 224. The fourth row shows Checkerboard Illusion input on the left. The right shows the gaussian filtered image. The average intensities for the darker gray square is 123, and for the lighter square is 240. The bottom row shows Dungeon Illusion input; the right half shows the filtered image. The average intensities for the darker gray square is 180, and for the lighter square is 238.

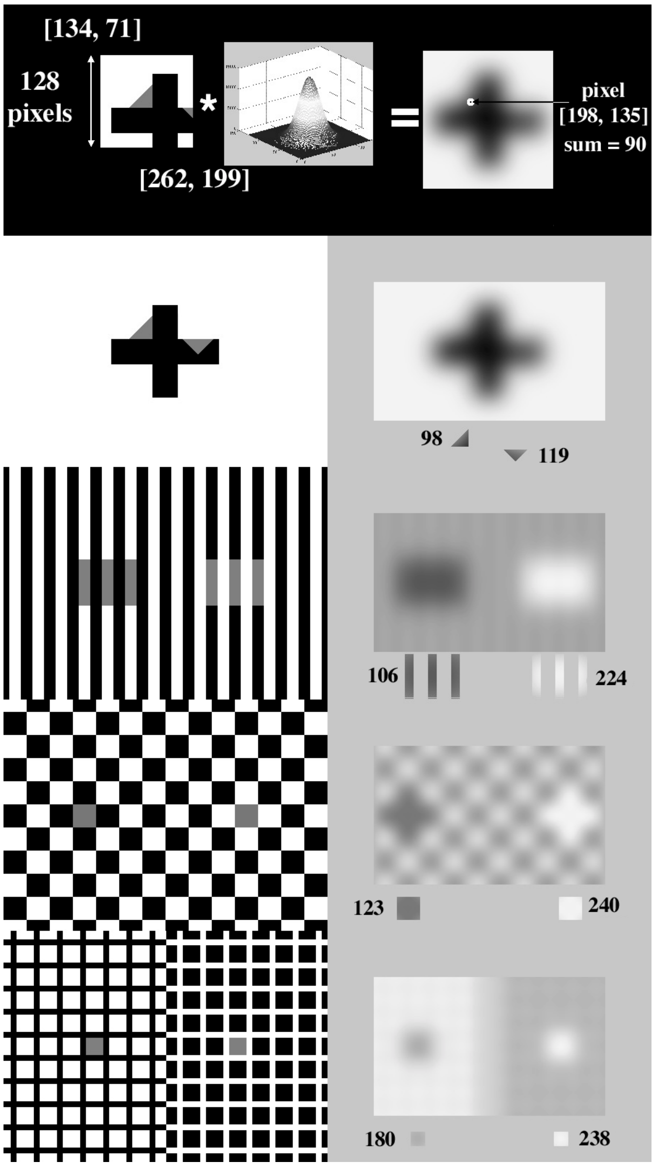


Figure 5 shows the analysis of four assimilation experiments using large receptive fields. The top row illustrates the process. A gaussian shaped integration filter calculates a pixel-by-pixel coarse spatial average of the original image. The second row shows Benary's Cross the third row shows White's Effect, the fourth row shows Checkerboard Illusion and the bottom row shows Dungeon Illusion. In all cases, the darker appearance on the left side of the input displays corresponded with lower average value. These areas look darker because they have lower average luminances in pooled receptor responses and low-spatial-frequency channels.

In all cases, the darker appearance on the left of the input displays corresponded with lower average value. These areas look darker because they have lower average luminances in pooled receptor responses and low-spatial-frequency channels.

Top-down cognitive mechanisms, as well as T-junction segmentation algorithms,[8] are not necessary to account for observed lightness shifts in assimilation experiments. Large receptive fields can account for the observations. There is ample evidence that large receptive field pools are present in the visual system. Hecht's threshold sensitivity[9], Hubel and Wiesel's cortical measurements[10] and Blakemore and Campbell's adaptation experiments[11] all demonstrate receptor pooling. The grays in the assimilation experiments correlate with sampled averages using very large pools.

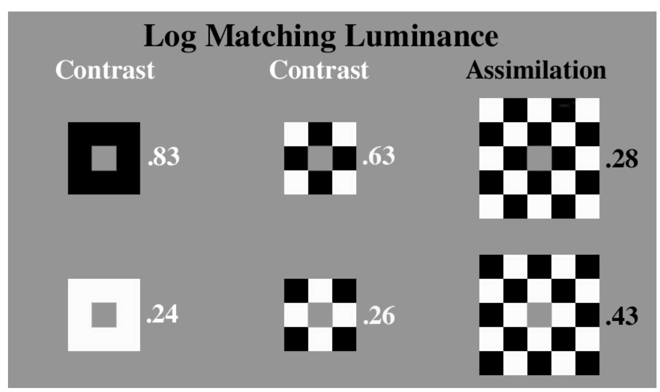
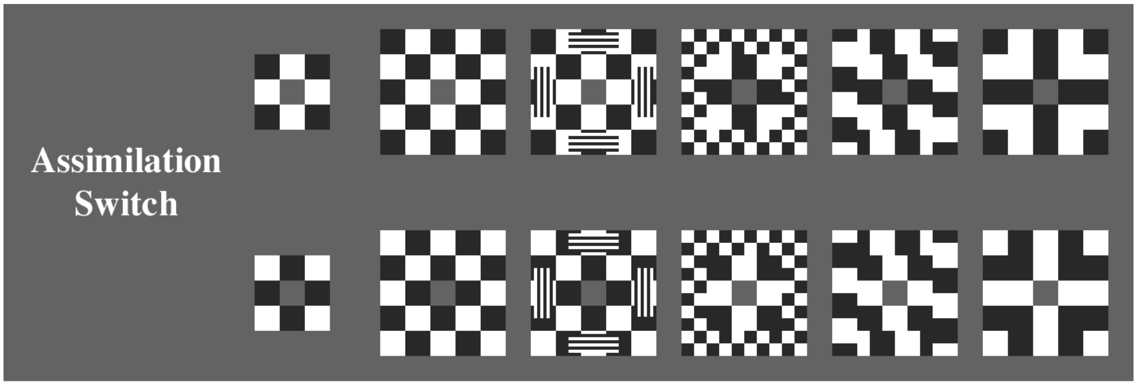


Figure 6 compares matching log luminaces for Simultaneous Contrast [left], segmented surrounds [middle] and the Checkerboard Illusion [right]. In simultaneous contrast observers match identical gray stimuli with 0.23 in a white and 0.83 in a black surround. With segmented surround, replacing diagonal segments with their opposites, the matches of 0.26 and 0.63 are very similar. Contrast is preserved. The checkerboard illusion adds a row of out-of-phase outer surround elements. Contrast is shut off, or is in equilibrium. Assimilation is observed because the matches have reversed [0.43,0.28].



% Assimilation

	Deg.	Min.						
MAM								
1	0.63	37.5	0%	0%	0%	0%	0%	0%
2	0.31	18.8	0%	44%	0%	0%	0%	0%
3	0.16	9.4	0%	100%	0%	0%	17%	0%
JMC								
1	0.63	37.5	0%	0%	0%	0%	0%	0%
2	0.31	18.8	0%	0%	0%	0%	0%	0%
3	0.16	9.4	0%	100%	0%	0%	0%	0%
			Contrast	**Assimilation**	**Contrast**	**Contrast**	**Contrast**	**Contrast**

Figure 7 shows forced-choice data for six different spatial patrterns at three different sizes. The observer's task was to identify which central gray was darker, thus identifying whether contrast or assimilation was observers. The first column identifies the observer. The second and third columns specify the size of the gray center in degrees and minutes. The fouth column shows the percentage of trials that assimilation was reported with segmented surrounds. The fifth column shows Checkerboard Illusion data. the remaining columns use rearrangements of only the outer surround. All rearranements have the same number of black and white pixels, only the position changes. The sixth column introduces lines. The seventh column has half-size squares. The eigth column shifts the squares. The ninth column shifts the phase of the squares. Observers report 0% assimilation for large displays. Strong assimilation effects are reported for the smallest-size chekerboard Illusion. All four similar displays disrupt the periodic properties and no longer exhibit assimilation. Assilation isvery sensitive to display size and periodicity.

Contrast /Assimilation Switch

In contrast, white edges make grays look darker; in assimilation, white edges make grays lighter. The antagonism is apparent when you compare the assimilation found in the checkerboard illusion and contrast found in the very similar 1357 and 2468 segment pair (Figure 6). The only difference is the outer rows of black and white segments. It is as if this outer-surround shuts off contrast, and lets assimilation be apparent. The outer surround must be a periodic addition to the 9 segment inner area. If the outer ring is replaced with equal areas of white and black in an aperiodic pattern, then contrast remains and assimilation is not apparent.

Figure 7 shows the data from a series of forced choice experiments in which observers were asked to identify which member of a pair of displays had a darker center. This choice identified whether contrast or assimilation was observed. The experiments studied the same six displays in three different scaled sizes. All were viewed on an 18.75 x 11.25 background. In the larger displays assimilation was not reported. In the smallest display the Checkerboard Illusion was reported by both observers to exhibit assimilation in 100% trials. Contrast was reported in 100% of trials when the outer surround was removed. What is more interesting, is that four different outer surrounds failed to exhibit assimilation. These four outer surrounds were made by swapping the positions of black and white pixels. They introduced narrow lines, smaller checkerboards, shifted checkerboards and changes in phase. They all disrupted the periodicity of the checkerboard and all exhibited contrast. Only periodic outer surrounds produce assimilation in checkerboards.

Discussion

These results bring to mind other experiments measuring human visual responses using variable numbers of cycles. As reported by Campbell and Robson[12], and many others, measurements of the threshold response to sinewave gratings gives a characteristic curve of contrast sensitivity vs. spatial frequency. Using the same apparatus and changing only the observer's viewing distance gives a family of different contrast sensitivity curves.[13] These curves are identical above 3 cycles per degree. Below that, each retinal size gives a different contrast sensitivity. These data do not correlate with cycles/degree, but correlate perfectly with the number of cycles sine wave. This produces a distance constancy effect in which the same low-number-of-cycles sinewave grating has constant visibility. Three cycles of sine wave is more visible than one cycle in threshold and contrast-matching measurements. This is an example of visual mechanisms responsive to extended spatial patterns.

The checkerboard experiments exhibit contrast when with a 3x3 pattern [1.5 cycle], and assimilation with a 5x5 [2.5 cycle] pattern. The introduction of non-periodic elements break the pattern and observers report contrast.

Summary

The human visual system has very complex responses to simple stimuli. Contrast is often described as a low-level response to light influenced by the average luminance of the surround, not requiring unconscious inference. The experiments here show that contrast is generated by a spatial mechanism . Contrast is observed when the displays are aperiodic and have unbalanced population of whites and blacks. There is no dependence on average luminance of the surround, only an extreme sensitivity to the placement of surround elements. There is no evidence that inference is required.

Assimilation is often described as evidence of inference, because it is the opposite of contrast. The experiments shown here show that assimilation can be explained by the simplest spatial mechanism, namely receptor pooling. Assimilation is observed in periodic displays with balanced white and black populations. Unlike contrast, it is sensitive to average luminance and insensitive to the location of edges. Rather than requiring inference to explain assimilation, these experiments raise interesting questions about the way assimilation displays put contrast to sleep.

Contrast is a complex spatial mechanism that is evident with simple center-surround displays. It can be shut off, and reintroduced by the spatial pattern of outer-surround elements. Assimilation in periodic displays is a simple mechanism found in the absence of contrast. It depends on the average value of very-large-receptive fields. None of the above experiments provide evidence to support unconscious inference as a visual mechanism.

Acknowledgments

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Biography

John McCann received his A.B degree in Biology from Harvard University in 1964. He managed the Vision Research Laboratory at Polaroid from 1961 to 1996. His work concentrated on research in human color vision, large format instant photography and the reproduction of fine art. He is a Fellow of the IS&T. He is a past President of IS&T and the Artists Foundation, Boston andis currently Secretary of the Inter-Society Color Council. He is a consultant and is continuing his research on lightness and color vision.