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Perceptual Adaptation in the Use of Night Vision Goggles

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I. Introduction

The image intensification (I^2) systems studied for this report were the biocular AN/PVS-7 (NVG) and the binocular AN/AVS-6 (ANVIS). Both are quite impressive for purposes of revealing the structure of the environment in a fairly straightforward way in extremely low-light conditions. But these systems represent an unusual viewing medium.

The perceptual information available through I^2 systems is different in a variety of ways from the typical input of everyday vision, and extensive training and practice is required for optimal use. Using this sort of system involves a kind of perceptual skill learning, but it may also involve visual adaptations that are not simply an extension of normal vision. For example, the visual noise evident in the goggles in very low-light conditions (e.g., those classified as moonless or cloudy night) results in unusual statistical properties in visual input. Because we had recently discovered a strong and enduring aftereffect of perceived texture density which seemed to be sensitive to precisely the sorts of statistical distortions introduced by I^2 systems, it occurred to us that visual noise of this sort might be a very potent adapting stimulus for texture density and produce an aftereffect that extended into normal vision once the goggles were removed. As the studies reported below will indicate, we have not found any experimental evidence that I^2 systems produce texture density aftereffects.

The nature of the texture density aftereffect is explained briefly below, followed by an accounting of our studies of I^2 systems and our most recent work on the texture density aftereffect. A test for spatial frequency adaptation after exposure to NVG's is also reported, as is a study of perceived depth from motion (motion parallax) while wearing the biocular goggles. We conclude with a summary of our findings.

The Texture Density Aftereffect

Perceived texture density can be described as the apparent number of texture elements per unit of visual area or as the average apparent distance between texture elements in some location. The paradigm we have developed for the establishment and measurement of a texture density aftereffect involves exposing different regions of the visual field to textures with different densities of elements. The aftereffect is quite strong (Durgin & Proffitt, 1992).

An illustration of the texture density aftereffect, with instructions for experiencing a short term version of it, is provided in Figure 1. The magnitude and the duration of the aftereffect varies from person to person, but across a variety of manipulations we typically produce an mean aftereffect size of about .75, by which is meant that a texture presented in a high-density-adapted region is perceived as equivalent in density to one (presented in an unadapted regions) with only three-quarters as many dots. For some observers the perceived density can be as low as one-third the actual density.

The short term version of the effect that may be experienced using Figure 1 will only last for a few seconds. However, the aftereffect can be quite enduring when exposure to the adaptation fields is extended over time. Subjects run in our adaptation procedures evidence strong aftereffects ten minutes after adaptation, and may show strong residual aftereffects after an hour or more. With repeated exposure to adaptation procedures, even longer term aftereffects may be produced which can last for days.

Long Term Aftereffects

The physiological basis for the texture density aftereffect is unknown. Because the long term aftereffect can last for hours or even days subsequent to adaptation, it is unlikely that it is the result of neural fatigue of an hypothesized density-detection system. The two most prominent accounts of long term aftereffects generally are recalibration and classical conditioning which have both been proposed for contingent color aftereffects (Dodwell & Humphrey, 1990; Siegel, Allan, & Eissenberg, 1992). If texture density aftereffects are due to a local recalibration of the density detection system's output, then we expect to find no context-specific effects: an aftereffect generated in one condition should transfer to all other circumstances. On the other hand, a classically conditioned aftereffect might remain bound to any number of contextual conditions. In order to understand the consequences of aftereffects resulting from special imaging devices, it is therefore important to consider whether conditioning or recalibration is the best explanation of the effect. If the aftereffect is a recalibration of the visual system with respect to the dimension of texture density, then an aftereffect generated in one circumstance will transfer to any other. However, it is also possible that that the visual system forms an adaptation effect that is cued to certain contextual elements. In the latter case, aftereffects need not transfer between viewing conditions, and the special adaptations appropriate to one display media need not interfere with normal vision.

II. Investigations of I^2 Systems and Texture Density Perception

The visual noise produced in an I^2 system appears as a random firing of pixels of the display (with greater and lesser intensity). Because the noise is of high temporal and spatial frequency it is usually of little consequence in the interpretation of the gross structure of the environment. In biocular (NVG) goggles a single light amplifying tube is used, so identical noise is presented to both eyes. In binocular (ANVIS) goggles, the noise in the two eyes is decorrelated. In neither case is the visual noise consciously mistaken for a part of the environmental surfaces. However, the statistical properties of the images in these goggles is reminiscent of a very high-density scatterdot texture such as those used to produce texture density aftereffects.

Experiment 1.

In order to determine whether the use of I^2 systems affects the subsequent perception of texture density, we trained four observers to criterion in the recognition of 6 categories (discrete levels) of density. Examples of these categories are shown in Figure 2. The observers then used the night vision goggles in lighting conditions such that the surface structure of the environment was clear, though a great deal of visual noise was quite noticeable. After 40-60 minutes of wearing the goggles, subjects were asked to identify instances of the previously learned density categories. If exposure to the visual noise produced an a distortion in subsequently perceived density, then we would expect to have found a shift in the identification of category instances consistent with a decreased perceived density. In fact we found no evidence of a shift.

Experiment 2.

Although the result of the first experiment suggested that visual noise did not produce density aftereffects, it remained possible that our measure was simply not adequately sensitive. In a second experiment we trained twelve observers in a simpler task of indicating whether a texture presented on a given trial was more or less dense than a standard. This kind of measurement gave us information about sensitivity (jnd) as well as absolute registration of density relative to some standard. Subsequent to I^2 system visual noise exposure, subjects did not evidence any shift in absolute judgment, nor in sensitivity.

Experiment 3.

Because of our failure to establish evidence for a full-field density aftereffect after exposure to visual noise, we decided to attempt to produce an adaptation situation more similar to our density adapting paradigm. As was illustrated in Figure 1, the traditional paradigm involves exposing only one part of the visual field to a high density texture. In Experiments 1 and 2 the level of visual noise was high, but constant across the whole visual field. In the present experiment, different levels of visual noise were provided to different parts of the visual field.

Because the visual noise in an I^2 system is additive, it is more apparent in darker environments. In order to provide different levels of visual noise to different regions of the visual field, a split-screen apparatus was designed in which one portion of the visual field was illuminated by LEDs while a second, lower portion was left quite dark. A schematic of the apparatus is shown in Figure 3. Subjects were required to center their gaze just above the dark region. Partly to help maintain interest and attention during the ten-minute adapting period, subjects were required to make depth judgments about a set of three-dimensional stimuli using motion parallax information provided by side to side head motion in a sliding chin rest. The biocular NVGs were used for this experiment.

Eight subjects were assessed for density matches in the upper and lower portion of the visual field before and after exposure to the adaptation period. The results of the experiment are represented in the upper line of Figure 4. It is evident that no clear aftereffect resulted from the use of the NVGs. The second line in Figure 4 represents aftereffect data from a study in which subjects were exposed to fifteen minutes of intermittent texture-density adaptation using computer-generated scatter-dot textures while making distance judgments. This data is shown here for comparison purposes.

Conclusion

In three experiments we failed to find evidence that exposure to high levels of visual noise in an I^2 system produces a recalibratory distortion of the texture density system. Although the time of exposure to the goggles was relatively brief compared to the extended usage for which they are intended, similar temporal exposures to scatter-dot textures do produce readily measurable distortions of density perception.

III. Other Aspects of Vision Investigated

Studies of Depth from Motion

We have tested subjects who used biocular I^2 systems for whether they could accurately discriminate the size of objects using motion parallax cues. Motion parallax alone is an excellent basis for perceiving the form of an object, though not its absolute size in depth. Using the stimulus apparatus of Durgin, Proffitt and Reinke (1992), the perception of size in depth was investigated while subjects wore NVGs. Under normal viewing conditions, motion parallax estimates of object size show discrimination between sizes, but poor absolute size judgment. In the NVG condition we found very poor discrimination of size. This is a fairly strightforward result of added noise.

Spatial Frequency Detection

The visual noise in the NVG image is of high spatial frequency and seems likely to produce adaptation of spatial frequency channels. We ran a study of threshhold for detection before and after using the NVGs. Although there is an immediate increase in threshhold for detection for all stimuli after removing the goggles, the visual system recovers within a few seconds and shows no evidence of threshhold elevation for any range of spatial frequencies, including the range involved in the NVG displays. De Valois and Switkes (1980) have found that scatterdot textures do not produce expected spatial frequency adaptations either. These findings may speak to the issue of contextually cued calibration sets which are learned in unusual imaging conditions.

IV. Investigations of the Content and Character of Texture Density Aftereffects.

Concurrent with our direct tests of I^2 systems, we have been following several lines of exploration of the nature of the density aftereffect. The first line of investigation has been an attempt to isolate and characterize the perceptual dimension affected by density adaptation. An ultimate goal of this research would be to understand whether visual noise simply does not serve as a stimulus for the texture density system--a question to which we do not feel we yet have an answer.

The second area of concern is to understand the nature of the long term density aftereffect. Two lines of experimentation are reported here in this regard: generation of the long term density aftereffect and interocular transfer of the effect. A convergent goal of these lines of research is to understand what sort of process is responsible for long term aftereffects of density perception.

Density as a Visual Dimension

The dependent measure in most of our assessments of density adaptation is the number of dots in a given region. This serves a clearly quantifiable measure of aftereffect size, and generally shows a constant level of aftereffect across the range of densities we generally test. However, the phenomenological effect of density adaptation is not limited to a quantitative decrement in perceived numerosity. What is perceived is both a distortion in the average interdot distance and a reduction of apparent clustering of dots.

In order to demonstrate the dissociability of density and numerosity, we performed an experiment in which the same adaptation and testing procedures were administered to two sets of subjects, except that the instructions to the subjects differed. One group was instructed to compare the test stimuli purely on the basis of the apparent number of dots. This group was told to ignore the configuration of the dots and to simply judge which texture field had more. The second group was told to compare the fields for relative density or clustering of dots and to ignore the absolute number of dots. The levels of numerosity tested ranged from 20 to 320. As with prior experiments, the dependent measure of the experiment is number of dots required to match the field presented in the high-density adapted region. The difference between the two groups is solely in the verbal description of the dimension along which they are to compare the textures.

The results of the experiment are shown in Figure 5. For 20, 40 and 80 dots, the match on the basis of numerosity is quite different from that on the basis of perceived density or clustering. Indeed, density adaptation seems to have little effect on the judgment of numerosity for 20 dots, though the perceived configuration of 20 dots is affected in the same ratio as all the other levels of density. The plot is shown on log-log coordinates in order to illustrate that the distortion of density/clustering produces a consistent ratiometric response compared to the actual number of dots presented. The matches from the numerosity group seem to tend toward those of the density group as the number of dots increases.

This illustration of the psychological dissociability of numerosity and density is an important step in characterizing the information underlying the texture density aftereffect. We plan to further investigate characterizations of the information underlying density perception by trying out different kinds of dependent measures, such as a direct manipulation of clustering, as defined by Ginsburg and Goldstein (1987). We are also curious to understand if it is the lack of configural information in dynamic visual noise that makes it an unsuitable adaptation stimulus for texture density aftereffects.

Interocular Transfer of Texture Density Aftereffects

Interocular transfer refers to the monocular measurement of an aftereffect in one eye subsequent to the monocular adaptation of the other eye. The interocular transfer of an aftereffect seems like a good indication that the site of the adaptation is beyond the point where the pathways from the two eyes merge, though the absence of transfer does not mean that the effect precedes this point. For example, in a recalibration model of the McCollough Effect (a contingent color aftereffect that does not normally show interocular transfer) the fact that the recalibration of color perception ought to be independent for the two eyes is a sufficient functional account of non-transfer that the structural location of the effect is taken to be irrelevant. Because some contingent color aftereffects have been found to be contingent upon semantic content (Allan, Siegel, Collins, & MacQueen, 1989) it seems unlikely that these effects are limited to regions structurally prior to the merging of inputs from the two eyes.

In our experiments on interocular transfer of the texture density aftereffect we generally find transfer: If an observer is adapted to textures presented to one eye while the other eye receives equivalent luminance but no textures, subsequent assessment in either eye will reveal the same level of density aftereffect. Figure 6 shows the results of an experiment of this nature. This in itself is a fairly straightforward finding of interocular transfer. On the other hand, if the unadapted eye is covered with an eye-patch during adaptation and then assessed subsequently while the originally adapted eye is patched, some subjects demonstrate strong transfer (equivalent to the level obtained if the originally adapted eye is assessed) but others show an absolute absence of transfer. Figure 7 shows the results of two experiments in which the eye-patch manipulation was used (the methodologies employed in the two experiments were slightly different).

If it were true that no subjects showed transfer when no light was provided to the unadapted eye, then a reasonable recalibration account would be possible. What is striking about the mixed finding is that the variable effect of having one eye patched suggests a hidden factor in the perceptual system's response to adaptation. One plausible account of the lack of transfer is that the long term density aftereffect is a classically conditioned response which transfers to new contexts only insofar as the context is not classified as novel. It might be the case that an eye-patch is less salient for some observers than for others, for example. On the other hand, it might be that ocular dominance or rivalry is the hidden factor.

At present we can draw no conclusions regarding the final explanation of this apparently anomalous result, but it is suggestive of a classical conditioning account and of the possibility that aftereffects generated in one context may not transfer to another--which is relevant to our attempts to find a density aftereffect after exposure to NVGs.

Variability in the Production of Long Term Aftereffects

Related to the mixed findings regarding interocular transfer are some findings regarding the production of a long term density aftereffect. In our typical adaptation paradigms, subjects are readapted between each test trial for a few seconds to reestablish the aftereffect for measurement. In subsequent posttests, (to assess the presence of interocular transfer, for example,) no readaptation is used. Although the strength of the aftereffect generated may vary between subjects in both the initial adaptation phase and the posttest, the presence of a clear aftereffect in the posttest condition is consistent between subjects. However, if the adaptation period consists solely of a lengthy exposure to repeated flashes of adaptation stimuli, we have found considerable variability between subjects as to whether an aftereffect is established. Alternatively, if an irrelevant task is incorporated into the adaptation procedure (such as judging the relative position of two dots), then a strong aftereffect is generated only when the textures used for adaptation are high in luminance contrast (white dots on a black screen). Figure 8 shows data concerning the level of aftereffect produced while performing irrelevant tasks or no task during adaptation. It is evident that both stimulus contrast and task relevance affect the generation of the aftereffect. Both manipulations may affect attention: Contrast may produce an orienting response, and task relevance may affect the distribution (or availability) of attentional resources.

Because the visual noise in NVG displays is relatively low-contrast. it may be that no long term adaptations will be produced so long as attentional resources are devoted elsewhere--such as toward mapping the surface structure of the environment.

V. General Conclusion

The image information while wearing the Night Vision Goggles includes a high noise/signal ratio which is simply a characteristic of the technology. The use of the goggles is not entirely a natural extension of daytime vision, and might, in theory, induce modifications of perceptual functioning which are detrimental to performance in normal conditions. Our goal has been to determine whether the visual noise in the images viewed through the goggles may produce aftereffects in the perception of texture density. The results of our studies reported here demonstrate no evidence of potentially harmful aftereffects of using I^2 systems.

As the aftereffect we are studying is not fully understood, we are left with a variety of explanations for our negative findings so far. (1) Our studies indicate that texture density adaptation responds to configural information rather than simply quantity (numerosity) of input. Visual noise does not seem to include configural information, and may be simply inadequate to produce an aftereffect--or may produce a very different kind of aftereffect. (2) The production of a long term density aftereffect seems to depend upon a number of factors, including luminance contrast. Why this is so is not well understood, but it may involve attention and the assignment of cognitive resources. (3) We currently find a simple recalibration model inadequate to account for our data, but have not yet determined the important parameters of the (less well defined) model of the aftereffect as a conditioned response. It may be that the viewing conditions can be "taken into account" by the visual system.

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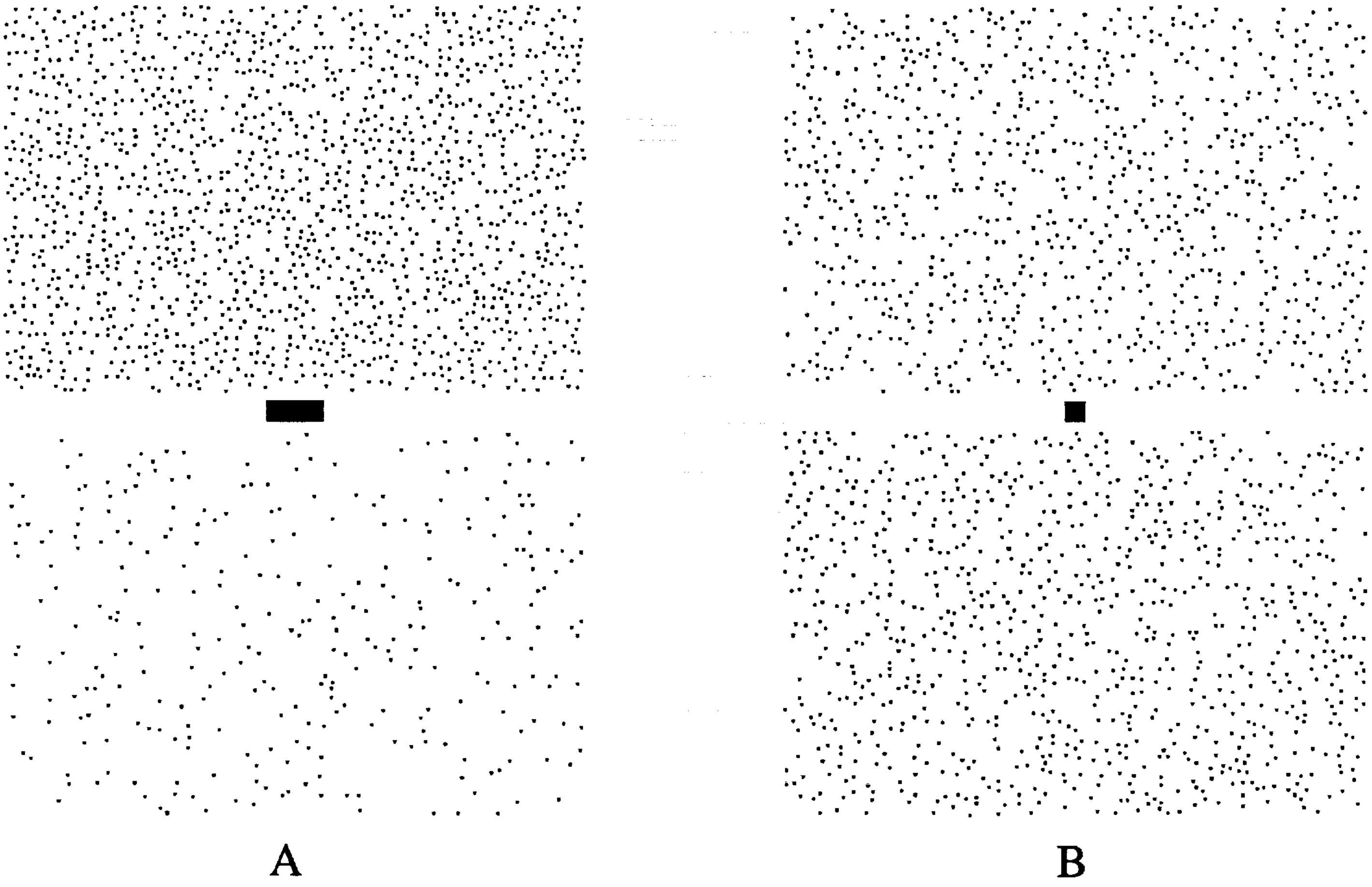
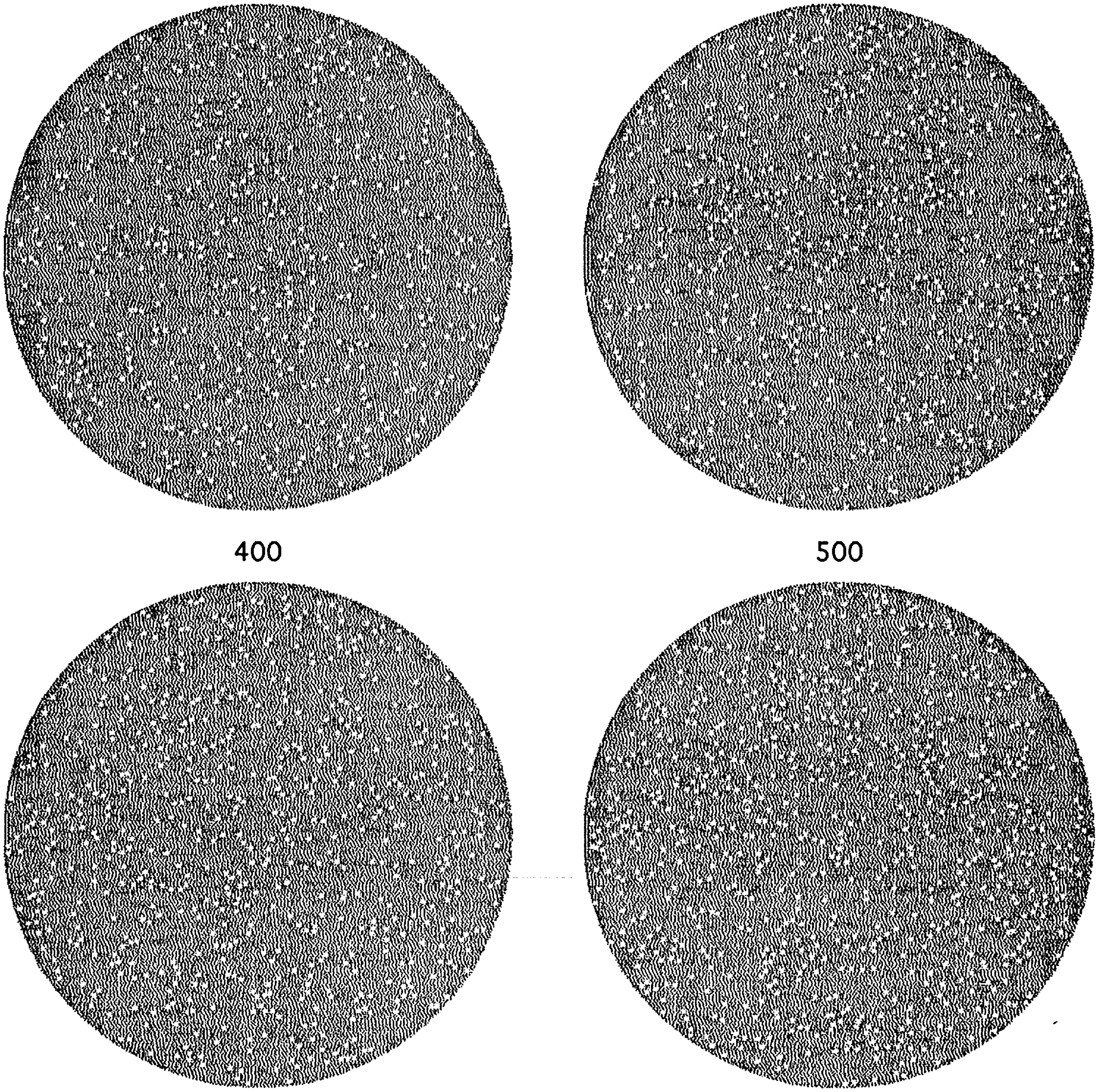


Figure 1. Prototype of texture density aftereffect. To experience the density aftereffect, first examine the textures in Panel B. The density of texture elements above and below should appear about equal since one is a 180° rotation of the other. Next fixate the central bar in Panel A, allowing your eyes to scan back and forth along the bar. After several seconds, shift your gaze to the fixation mark of Panel B and compare the apparent densities of the two fields. Observers report that the upper field of Panel B seems markedly less dense than the lower after adapting to Panel A. In a typical adaptation paradigm, texture fields like those in Panel A would be presented, one per second, during adaptation, and the resulting point of subjective equality between textures presented above and below would be determined by an adaptive (staircase) method.



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700

Figure 2. Examples of texture-density categories used in experiment to test for density aftereffect. Subjects were trained to identify categories of density and then exposed to high levels of dynamic visual noise through the use of Night Vision Goggles. No systematic distortions of perception (category shifts) were found in subsequent tests.

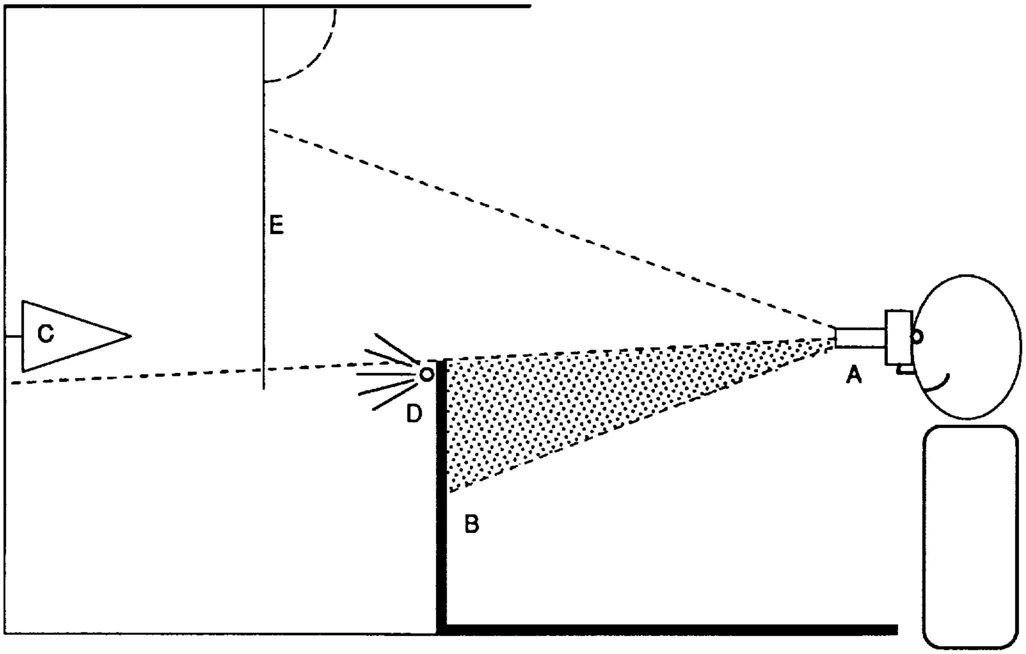

Figure 3. Split screen viewing apparatus used to expose different portions of the visual field to different quantites of dynamic noise. The subject wore biocular Night Vision Goggles, (A), and could slide only to the left and right, to produce motion parallax. The lower portion of the visual field was exposed to a very dark surface, (B), while the subject made depth judgments about one of four cones, (C). An LED, (D), illuminated the cone and its surrounding surfaces, as well as the screen, (E), that was lowered between trials. The relative quantity of dynamic visual noise in the upper half of the visual field was quite low. If the dynamic visual noise in the NVG display produced a density aftereffect, the lower portion of the visual field should have been differentially adapted. No aftereffects were found.

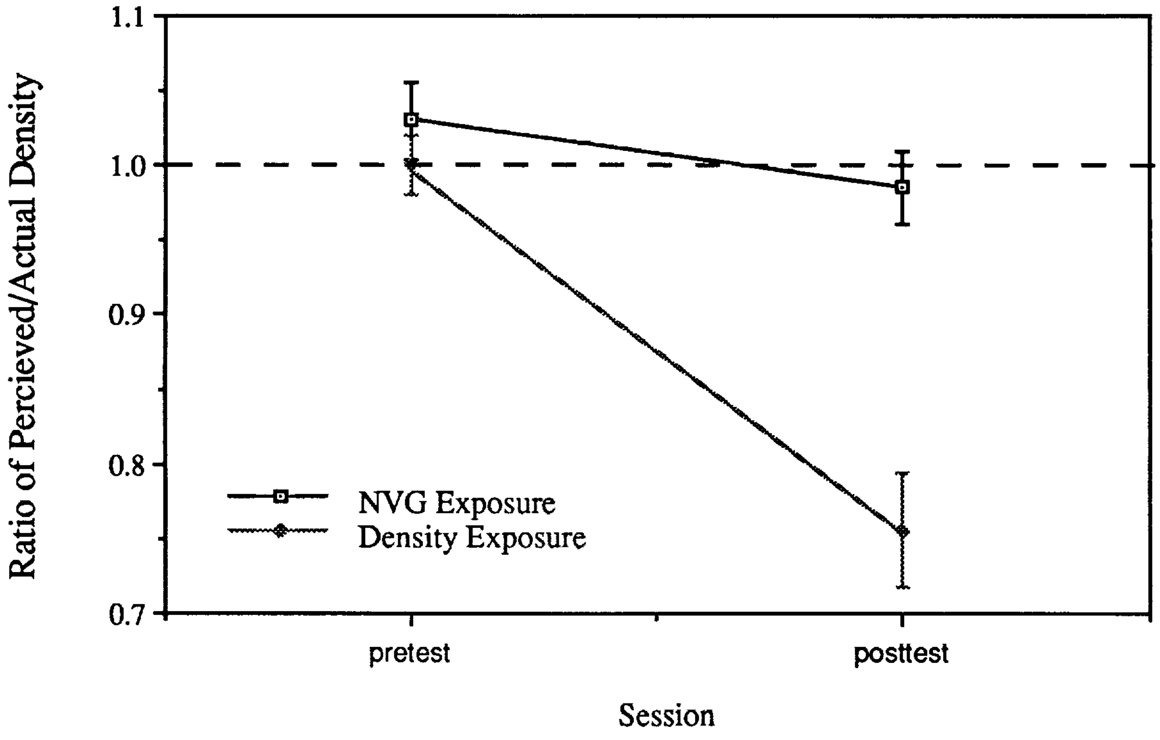

Figure 4. Results from the "Split Screen" experiment. Subjects exposed to high levels of visual noise through Night Vision Goggles show no significant distortion of density perception in posttest assessments of relative density perception. A positive aftereffect result is shown here for comparison: Subjects in the Density Exposure condition were adapted to differential densities while making distance judgments.

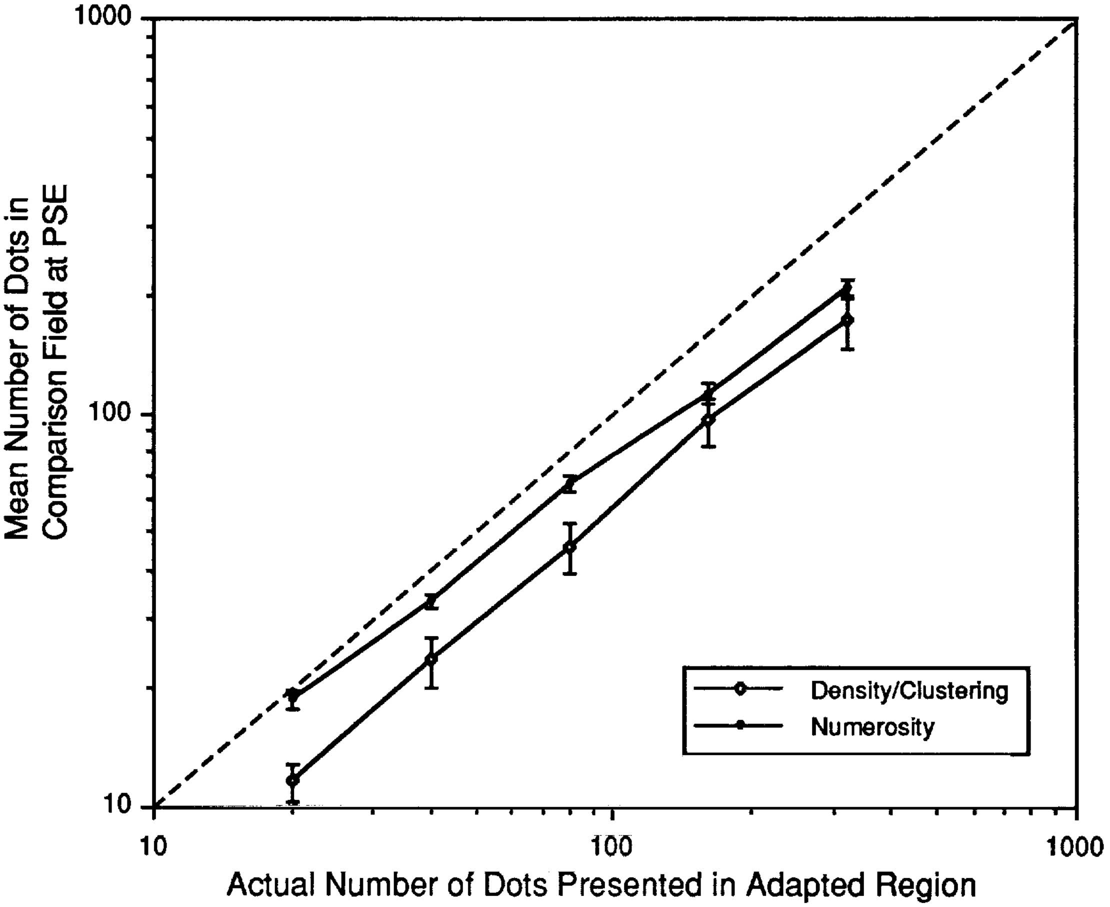

Figure 5. A log-log plot of the points of subjective equality (expressed in number of dots) for judgments made along two different perceptual dimensions -- numerosity and density/ clustering -- when observers are texture-density adapted. Apparent numerosity is only weakly affected for low dot numbers, while density/ clustering is affected equally at all levels of density tested. There were ten observers in each condition.

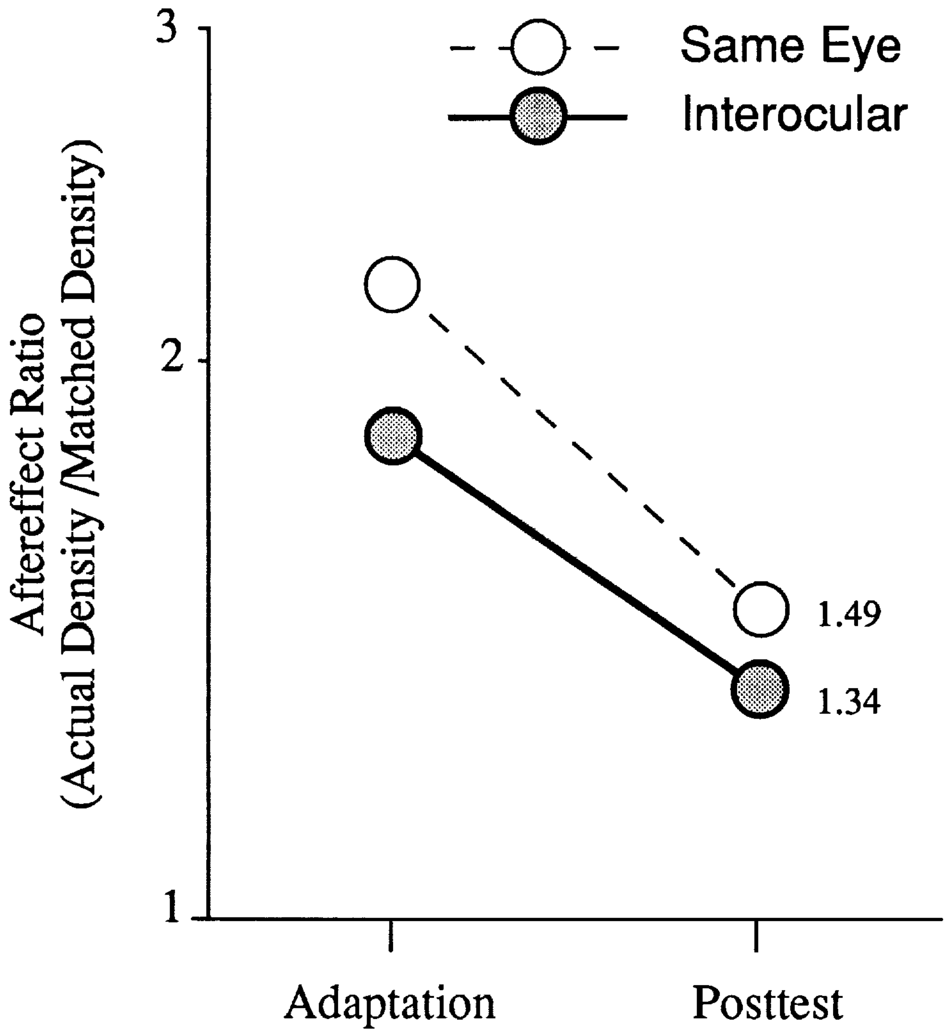

Figure 6. Results of interocular transfer experiment: Eight subjects were monocularly adapted with balanced dot textures through a stereo viewer. The fixation mark was presented against a grey background binocularly, but the adaptation and test stimuli were only presented to one eye. Four of the subjects were then retested in the same eye as had been originally adapted. The other four were tested for interocular transfer by switching the eye to which the stimuli were sent in the posttest. All subjects showed evidence of a long term aftereffect whether tested interocularly or in the same eye.

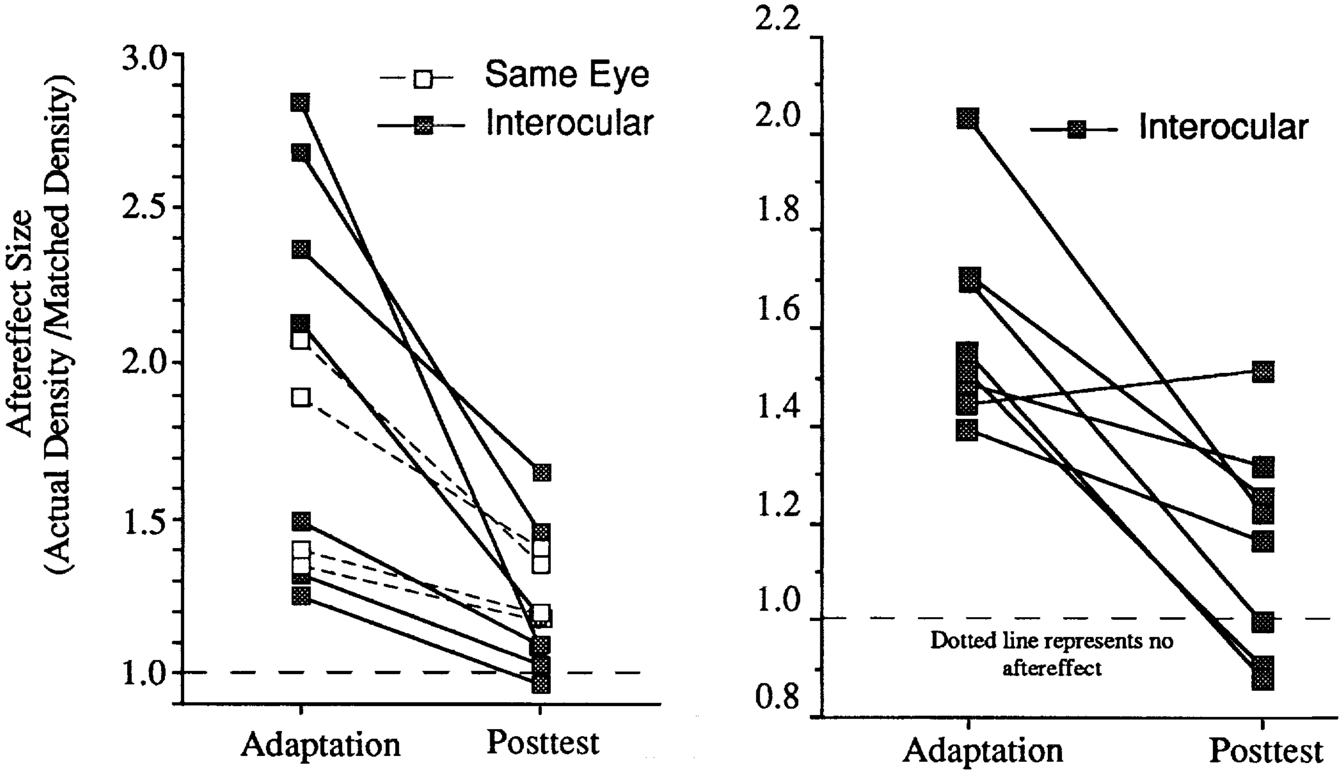

Figure 7. Results of two experiments (differing slightly in methodology) investigating interocular transfer of density aftereffect when unadapted eye is occluded by an eye-patch. In the left figure, seven subjects are shown in the interocular transfer condition; 4 controls (same eye) are also shown. In the right figure, the data of eight further interocular transfer subjects are shown. Across the two experiments there were eight subjects tested interocularly who demonstrated little or no aftereffect when the unadapted eye was occluded by an eye-patch during adaptation. However, seven did demonstrate transfer even in this condition.
(From Durgin & Proffitt, May, 1992)

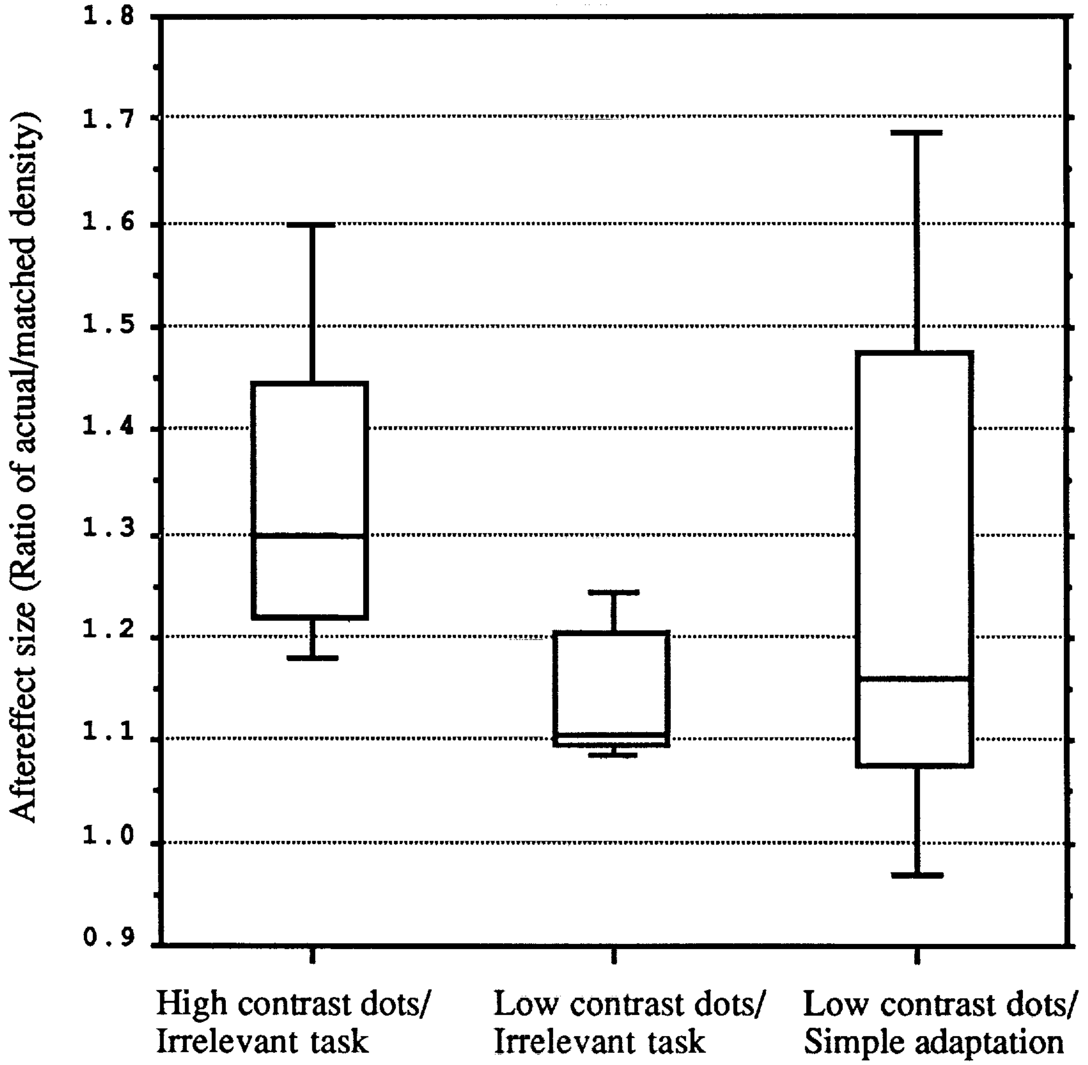

Figure 8. Boxplots portray the effects of dot-contrast and task-relevance on formation of long term density aftereffect. High-contrast textures (white dots on black) reliably produce strong aftereffect of density perception, even when an irrelevant task is performed during adaptation. For low-contrast/ high-spatial frequency textures (luminance-balanced dots on gray), very weak aftereffects are found when an irrelevant task is used. When no task is performed during adaptation, performance is quite variable for low-contrast textures--perhaps reflecting attentional differences of subjects. Adaptation in each case is for ten minutes. Aftereffect is assessed shortly after adaptation by (staircase) matches between textures presented in adapted and unadapted regions of the visual field.