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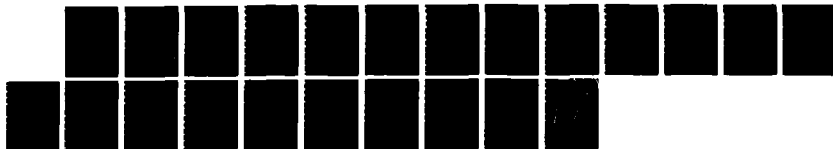
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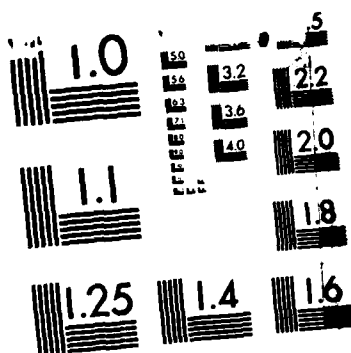
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19. Abstract

The main thrust of this research effort has been investigation of the spatial and temporal properties of the visual processes underlying relative spatial localization by human observers. The initial tasks were development of a suitable laboratory display system for generating the required stimuli, and development of appropriate experimental paradigms for studying the localization of widely separated objects. The second task was to make careful quantitative measurements of the spatial and temporal properties of the system underlying localization of widely separated objects. It was found that many of the stimulus manipulations that are critical in determination of contrast detection thresholds have little or no effect on localization accuracy. The relative localization of widely separated objects is a highly robust visual ability. Those variations in localization accuracy with changes in the spatial and temporal parameters of the stimulus that were obtained could readily be modeled as natural extensions of the threshold properties. The final task of this project was testing of existing models of spatial vision as they apply to the localization problem. We found that localization is a more complex visual ability than can be accounted for by current models of spatial vision. Specific extensions of the existing model were suggested by the data. *Keywords:*

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AFOSR Contract Number F49620-82-K-0024
Final Technical Report
October 1985

FINAL REPORT
SPATIOTEMPORAL CHARACTERISTICS OF VISUAL LOCALIZATION

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MATTHEW J. KEMPER
Chief, Technical Information Division

I. Research Objectives

The aim of the research covered by this contract was to study the process underlying the relative spatial localization of widely separated objects. (The localization of widely separated objects will subsequently be referred to as macrolocalization.) Specifically, the primary research was conducted on the following topics:

- The role of eye movements in macrolocalization.
- The relationship between macrolocalization and the localization of objects that are separated by only a few minutes of arc - i.e. hyperacuity targets.
- The spatial and temporal properties of the process underlying macrolocalization, with specific attention to the implications of the results of this research for models of localization and for understanding the relationship between macrolocalization and other spatial visual abilities.

II. Laboratory Facilities

Under this contract a flexible computer-controlled display system was designed and built in the principal investigator's laboratory at SRI. The system is based on an Apple II computer. The Apple II controls the details of the experiment, specifying the parameters for the stimuli, recording data, calculating the next stimulus value in staircase and adjustment procedures, randomizing stimuli, and giving right/wrong feedback to the subject. A 68000 coprocessor residing in the Apple is dedicated to sending visual pattern information to special-purpose hardware consisting of a hardware frame buffer and an analog board that generates the video signals required by the Conrac (2400C19) display monitor. This arrangement gives us a high degree of flexibility while being fast enough to switch from one pattern to a totally different one during the vertical retrace of the display.

The display field is 512 by 512 pixels, refreshed 60 times per second, non-interlaced. Each pixel is controlled by an 8-bit luminance value and a 12-bit contrast modifier. However, each line of the display is restricted to just two gray levels in three sequential segments: background, foreground, background. This is adequate for displaying a large assortment of points, lines, bars and gratings, and greatly reduces the information bandwidth requirements of most of the system.

In this system, stimuli are described in a convenient and powerful language created specifically for this task. The patterns include time as a dimension, specifying frame-by-frame changes of contrast or position, which may be repeated cyclically.

III. Research

A. Initial Work

While developing the laboratory facilities described above, the principal investigator did collaborative work with Dr. D. Regan of Dalhousie University, Nova Scotia. Several lines of research were pursued:

- **Temporal characteristics of the discrimination of objects on the basis of hue differences.** We found that discrimination is severely impaired in the absence of retinal image motion in all except the yellow region of the spectrum. This research was reported at ARVO in 1983.
- **Independence of orientation and spatial frequency in suprathreshold discriminations.** This was our primary research effort. It will be discussed in more detail subsequently.
- **Masking of spatial frequency discrimination.** Results of the earlier studies on suprathreshold discrimination suggested that the effects of masking on frequency discrimination should also be explored. Preliminary experiments revealed that whereas an orthogonal mask has no effect on frequency discrimination, a parallel mask has a profound effect, which varies with the relative spatial frequencies of the mask and test gratings. Dr. Regan completed this research in his laboratory, under his AFOSR contract.

B. Independence of Orientation and Spatial Frequency in Suprathreshold Discriminations

Several popular models of frequency-discrimination and of orientation-discrimination postulate that discriminability is a simple function of the difference in the responses of frequency- and orientation-tuned channels to the two stimuli being compared. In these models, the response of a given channel to the first stimulus is subtracted from the response of that channel to the second stimulus. Discriminability is then a simple function of the differences found in all of the postulated channels.

Dr. Regan and I tested these models by measuring frequency discrimination thresholds with like-oriented and with orthogonal grating pairs, and measuring orientation discrimination thresholds with grating pairs of the same spatial frequency and of very different spatial frequencies. The above models make no direct predictions about the results of these experiments, but they strongly suggest that discrimination thresholds should be impaired by the introduction of large differences in the dimension that is irrelevant to the task being performed. We found that there were no such differences. Orientation and frequency are independent at this discrimination stage of visual processing. These results suggest that units with similar spatial frequency characteristics but different orientation preferences are linked and that units with similar orientation preferences but different spatial frequency characteristics are also linked. This linking is not evident in the results

of either pattern adaptation or masking studies, but it is consistent with our hypothesis that discrimination occurs at a stage of visual processing subsequent to the initial representation by spatially-localized frequency and orientation selective units.

Results of these experiments were reported in a paper in JOSA in 1984.

C. Early Work on Spatial Localization of Widely Separated Objects

With the assistance of a part-time lab assistant, the principal investigator began the study of macrolocalization. The first studies in our new laboratory focused on identifying appropriate measurement techniques. Other than the research done in our laboratory, there is almost no literature on the subject of relative spatial localization of objects that are separated by more than about 10 or 20 minutes of arc, so there were no established experimental procedures.

We found that macrolocalization accuracy is not particularly sensitive to the spatial configuration of stimuli, but that, because of resolution limits and local spatial interactions, some configurations are inappropriate for use as small-scale stimuli, and hence, not suitable for experiments that compare macrolocalization and microlocalization directly. We also found that measurement of the temporal and spatial characteristics of macrolocalization requires extreme precision, both because sensitivity is very high and because extraneous cues can be readily used by the subject.

We soon gained sufficient experience with our experimental paradigms that we were confident of the generalizability and reproducibility of our results. We also replicated several microlocalization experiments and obtained results comparable to those reported in the literature, indicating that our experimental procedures were comparable, except in scale, to those used in other laboratories.

D. Spatial Characteristics of Macrolocalization-- Effect of Mean Separation

To provide a baseline for comparing the properties of micro- and macrolocalization and to guide the development of our model of localization, we measured localization accuracy with object separations ranging from less than 2 to more than 400 minutes of arc (min arc), using a 3-bar stimulus similar to that described above. We initially found that localization accuracy varies systematically with object separation in a manner that suggests the existence of several underlying mechanisms, each tuned to a different range of spatial separations. However, that result was obtained only in the absence of feedback. With right/wrong feedback supplied, performance was approximately constant with separation and equal to the highest level of sensitivity obtained without feedback.

One interpretation of these results is that the systematic variation in sensitivity without feedback reflects the presence of several underlying mechanisms, but that with feedback the subject

learns to make better use of the available information in the regions of transition between the mechanisms. Another interpretation is that performance varies because of interference from other visual processes, which are themselves spatially tuned, and that the subject learns to ignore these sources of interference when given appropriate feedback. With both of these interpretations possible, one can draw no inferences from these data about the distinctness of different underlying processes.

The main finding of this research was that, when expressed as a fraction of the mean separation, localization accuracy is nearly constant across object separations. That is, the "Weber fraction for localization", $\Delta s/s$, where s is the separation between the objects, is essentially constant with s . This result has profound implications for models of localization.

E. Spatial Characteristics of Macrolocalization--Number of Bars

We measured relative spatial localization accuracy with 2- and 4-bar stimuli over a large range of object separations, as had been done with the 3-bar stimuli described above. In the 2-bar condition, the subject learns a standard separation and does a mental comparison of the stimulus with that standard. In the 3- and 4-bar conditions there is no standard; the subject compares the distance between one pair of lines with the distance between a different pair.

There were several reasons for making these measurements: 1) to test the generality of the results obtained with 3 bars, 2) to investigate the problem of how the observer encodes the distance between objects, 3) to investigate whether a frequency-domain description of the localization system is appropriate.

We found that at all object separations tested, the number of bars has little effect on localization accuracy. Apparently, the mental representation of the standard separation is as accurate as a real-time judgment. These data provide evidence that 1) our experimental task is not sensitive to the details of the stimulus configuration, 2) an observer can calculate and store an average distance between two objects with extreme accuracy, and 3) since accuracy is not improved by the addition of more bars, no support is provided for a frequency-domain representation.

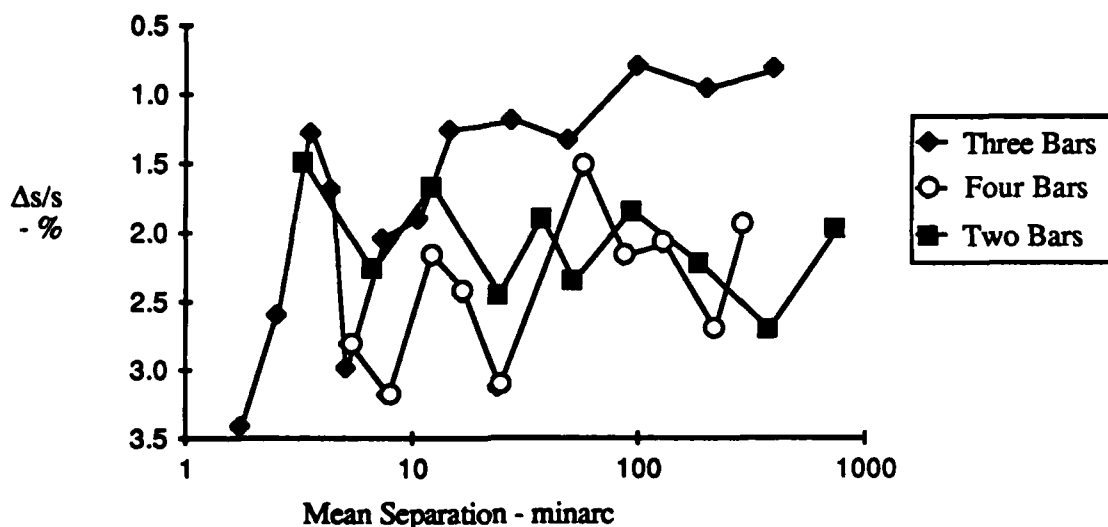


Fig. 1

These results are being included in a paper comparing localization with large and with small object separations. This paper is nearly complete and will soon be submitted to Journal of the Optical Society of America.

F. Temporal Characteristics of Macrolocalization-- Stabilization and Motion Effects

We measured the effects of retinal image stabilization on macrolocalization accuracy with a stationary stimulus and found that thresholds are elevated by nearly a factor of two. We also measured macrolocalization accuracy with stabilized and unstabilized stimuli that were 1) drifted very slowly (approximating the natural drift rate of the eye), 2) drifted more rapidly, or 3) moved abruptly between two retinal locations once every half second. We found that macrolocalization accuracy is essentially normal with fast drifts and abrupt shifts, but is much poorer when the retinal image moves very slowly (stabilized with very slow stimulus drift) or is static (stabilized with no stimulus motion).

Very slow drift of the otherwise stabilized stimulus, which restores contrast sensitivity to normal (Kelly, JOSA, 1340, 1979), fails to restore localization accuracy to normal. This implies that the effect of stabilization on macrolocalization is not due simply to a lowering of the apparent contrast of the stimulus. We confirmed this conclusion by measuring localization accuracy with an unstabilized stimulus whose apparent contrast was substantially lower than that of the original stabilized stimulus. This large change in contrast had little if any effect on macrolocalization accuracy. Thus the loss of apparent contrast that results from stabilization of the retinal image (Burbeck and Kelly, JOSA, 216, 1984) could not account for the decline in macrolocalization accuracy. Accuracy must have been reduced because of the temporal tuning of the

macrolocalization process itself.

The effects of stabilization on macrolocalization are different from the effects on microlocalization that have been reported previously by Keesey (JOSA, 769, 1960). However, comparison between these two findings may not be meaningful because the quality of image stabilization required for the microlocalization stimuli is probably not achievable in practice. Thus, the null result that Keesey obtained in the microlocalization condition may have been artifactual. Because of these potential artifacts, we adopted a different paradigm for comparing the temporal properties of small and large scale localization.

G. Temporal Characteristics of Localization--Exposure Duration

We investigated the effects of exposure duration on localization accuracy over a wide range of object separations. In this experiment, the subject was presented with a stimulus consisting of two identical, parallel, horizontal bars. The observer's task was to determine whether the separation between the bars was more or less than the average object separation he had seen on previous trials. The stimuli were presented for 100 ms, 400 ms, or for an indefinite duration (stimulus terminated by the observer's response); localization thresholds were measured for the three temporal conditions, for several mean object separations ranging from 6.7 to 400 minarc.

Results for two observers are shown below. Localization accuracy declines with decreasing exposure duration at the smallest mean separations used, consistent with previous studies of the effects of exposure duration on hyperacuity (e.g., Baron and Westheimer, JOSA, 212, 1973). However, for mean separations larger than about 25 minarc, exposure duration has no effect after 100 msec. (At exposure durations less than 100 msec, contrast integration plays a major role in the results.)

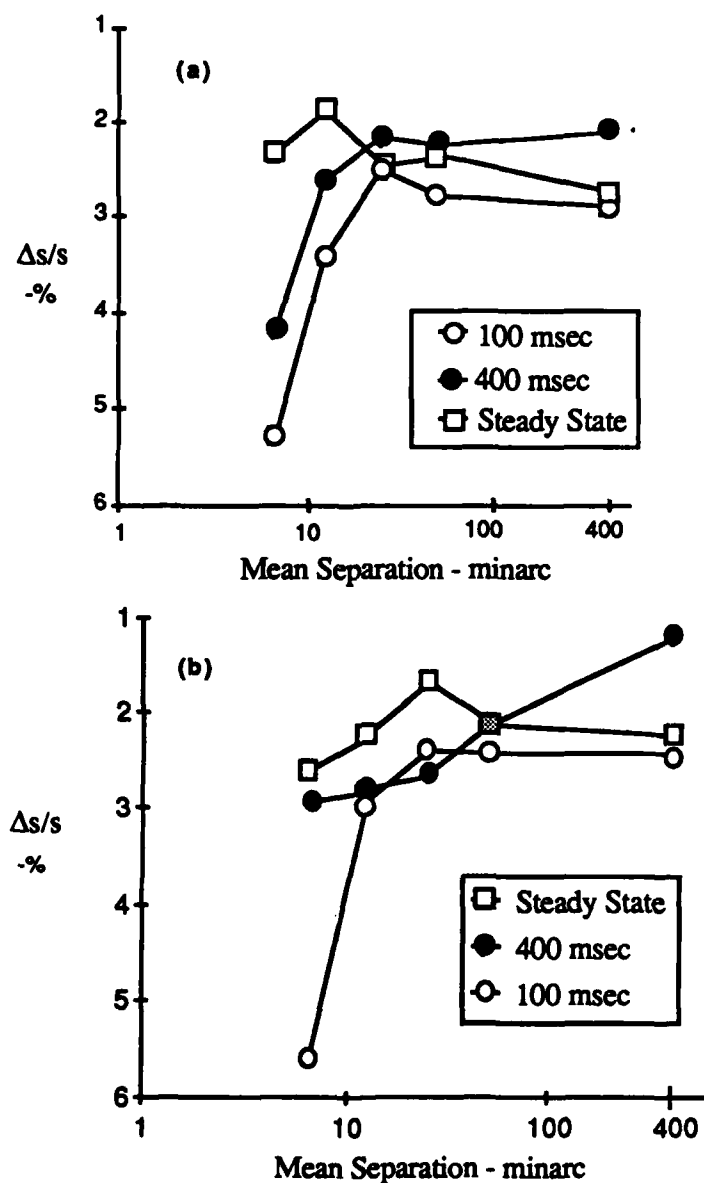


Fig. 2

This pattern of effects is similar to that obtained previously for contrast detection thresholds (Nachmias, JOSA, 421, 1967): Large exposure duration effects were obtained at high spatial frequencies and smaller effects at low spatial frequencies. Thus, our results appear to be consistent

with a frequency-channel model of relative spatial localization in which hyperacuity stimuli are localized by high spatial frequency mechanisms and more widely separated stimuli by low spatial frequency mechanisms. To test this spatial frequency channel model of localization, we repeated the exposure duration experiments with a pair of widely separated, high-frequency bars. Each bar consisted of a high frequency grating whose contrast was modulated by a Gaussian envelope. The frequency of the gratings was 22 cycles/degree, and 8 cycles of the grating were visible to the observer under the Gaussian envelope. Results for this condition were similar to those obtained in the 7 minarc condition, even though the bars were separated by 175 minarc: Localization accuracy for the high frequency bars was significantly impaired at both 100 and 400 msec relative to the steady state condition. We concluded that the exposure duration effects occur at a stage of visual processing that is distal to the site of the localization judgment, and further that localization of widely separated objects is not, in general, performed by low spatial frequency mechanisms.

That the exposure duration effects shown above were not simply contrast effects was verified in the following experiments.

H. Contrast Effects and Frequency Channel Models of Localization

In this project, we were interested in determining the effects of contrast on macrolocalization. As a first step in this determination, we measured both macrolocalization accuracy and the probability of detection as functions of stimulus contrast, using a 2-bar stimulus with a mean separation of 175 min arc. Stabilization was used to control retinal location of the stimulus, and brief presentations were used to minimize fading.

Localization accuracy is not readily measurable at the detection threshold because on most trials only one bar is detected. At 1.5 times the detection threshold, both bars were detectable on most trials, so localization accuracy could readily be measured at that contrast and higher. We found that localization accuracy improves steadily as stimulus contrast is increased from 1.5 times to 5 to 10 times threshold. (This is a lower range of contrasts than was used in the experiments on the effects of stabilization.) We also performed comparable experiments with raised sine bars, which have less energy at high spatial frequencies than do the bars with rectangular profiles that were originally used. The results were unchanged, demonstrating that the increase in localization accuracy with contrast is not due to high-frequency information becoming suprathreshold with increasing contrast, as has been suggested for hyperacuity targets (e.g. Carlson and Klopfenstein, *JOSA*, 1974, 1985). A control was also run in which the width of the rectangular bars was reduced to be more comparable to the perceived width of the raised sine bars. These data are shown in Fig. 3 below.

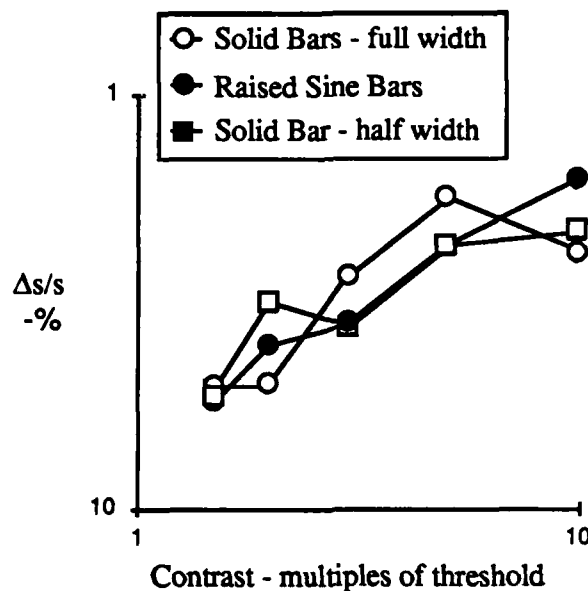


Fig. 3

To assess the effects of contrast in the exposure duration results and to test further the frequency channel model of localization, we measured localization accuracy as a function of stimulus contrast for bars consisting of many cycles of a horizontal high spatial frequency (with either a square or Gaussian vertical contrast envelope), and also with a white bar/black bar pair. None of these manipulations affected the shape of the localization accuracy vs. contrast curve. (Localization accuracy for the high spatial frequency bars with Gaussian envelope could be measured only over a very limited range of contrasts because of the high contrast detection thresholds for these stimuli.) We found that macrolocalization accuracy increased with stimulus contrast (expressed as multiples of the contrast detection threshold for each stimulus) in the same way for all stimuli used. However, the curves for the high frequency, Gaussian-envelope, bars were shifted down relative to the other curves. This overall shift indicates that the exposure duration effects reported above were not contrast effects, but were specific to the temporal dimension.

At full contrast, with a longer exposure duration (subject terminated trial), localization accuracy was essentially as high for the Gaussian modulated, high spatial frequency bars as it was for the rectangular bars. A frequency channel model of localization could not account for this result: The low spatial frequency channels theoretically responsible for the localization of widely separated objects such as these could not detect the high frequency bars. On the other hand, a position model of localization, which could account for our ability to localize these objects, predicts that localization accuracy, Δs is independent of the separation between the objects, s , contrary to the observed relationship (as reported above). Thus, neither a frequency channel model or a position model can account for all of the observed results. This is an important observation because it requires substantial modifications or extensions of existing theories.

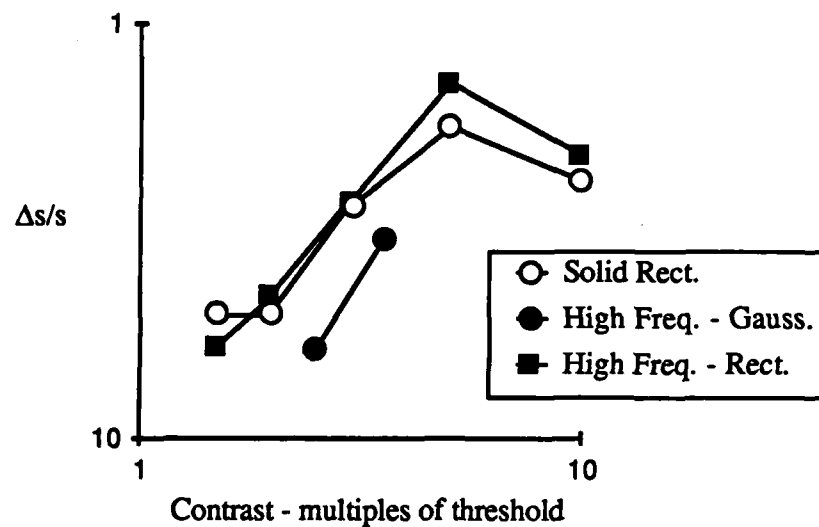


Fig. 4

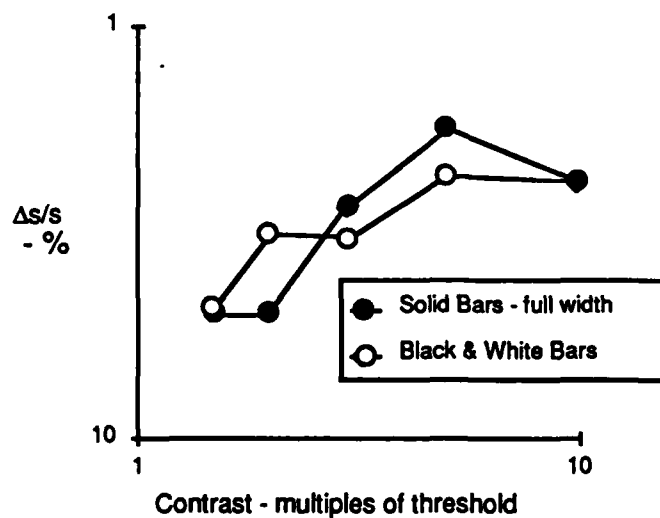


Fig. 5

Further evidence against the frequency channel model of localization is shown in Fig. 5. We know, from the results presented above, that localization accuracy is an approximately constant fraction of the object separation. Therefore, if localization were being performed by frequency channels, then changing the polarity of one bar should halve the peak spatial frequency of the

responsible channel, and hence double Δs . It does not; instead, localization accuracy is essentially unaffected by this manipulation of the stimulus.

Finally, a slightly curious aspect of the data shown in Figs. 3-5 is that the localization threshold is independent of the form of the bar only if the stimulus contrast is divided by the detection threshold (that is, if contrast is expressed as a multiple of the contrast detection threshold). Although there is nothing novel about using the contrast threshold as a normalizing constant, the procedure does assume that the gain of the system is proportional to the threshold, and we have no independent evidence that this is true.

To verify our previous findings that exposure duration has a large effect at small separations but not at large, we measured localization accuracy as a function of stimulus contrast over a wide range of object separations, using a 225 msec flash, as in the experiments just described. Results are shown in Fig. 6. The pattern of results at all object separations tested (down to 7 minarc) is the same as that shown in Figs. 3-5. At the smallest object separation, the localization vs. contrast curve was uniformly shifted down to lower accuracies, indicating that localization accuracy in this brief presentation condition is lower at a small than at large object separations, independent of the stimulus contrast. This result is consistent with a channel model of localization. (Although we have seen above that such a model is inadequate in other respects.)

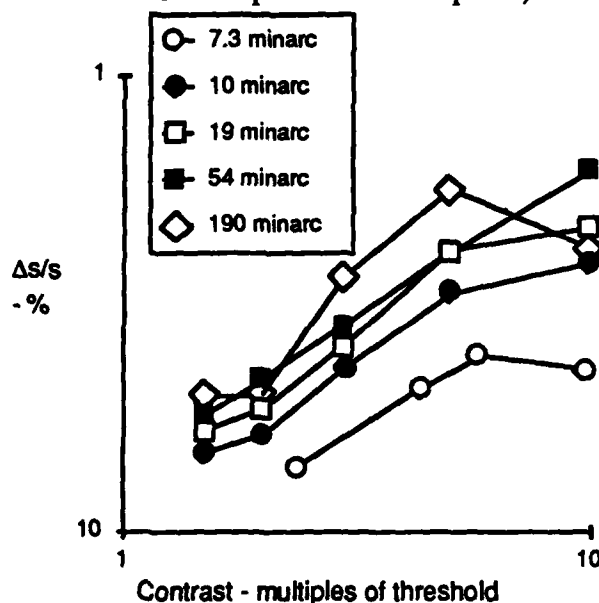


Fig. 6

The results reported above are being included in a paper on the properties of large-scale localization that is about to be submitted to Journal of the Optical Society of America

I. Effect of Orthogonal Extent

In this set of experiments, we addressed the problem of how the macrolocalization system calculates distances between objects. Because $\Delta s/s$ is constant, the shortest distance between two objects will provide the most accurate information. Can the macrolocalization system find and use this shortest distance? To address this question, we measured localization accuracy with 5 stimulus configurations. In each configuration there were two targets, which were separated by a variable distance vertically (100 min arc average). The subject's task was to judge whether the vertical separation was greater or less than the average separation. The upper target was always a small (4 min arc) dot that was centered horizontally on the screen. The lower target was either another small dot that was centered horizontally, a 48 min arc line whose left end point was centered horizontally, a 48 or 170 min arc line that was centered horizontally, or a line whose length and position varied randomly from trial to trial, with the constraint that some portion of the line must lie on the same vertical axis as the upper target (the dot). These stimuli were chosen to vary the amount of information available to the subject about the location of the orthogonal line connecting the stimuli--from very high, in the two dot condition, to very low, in the random-line-length condition.

We found that none of these stimulus manipulations significantly affected the subject's performance. Under all conditions, the subject was able to determine the distance between the targets with the same high degree of accuracy.

We were somewhat surprised by this independence of macrolocalization accuracy and orthogonal extent. To determine whether this was a general result or was specific to the horizontal and vertical orientations used, we repeated the experiments at 45 degrees, using a dove prism to rotate the image of the display. A circular surround and darkened room were used to eliminate extraneous orientation cues. We obtained the same results. Again, the subject had no difficulty in determining the most appropriate direction of measurement; his performance was as good with a dot and a line of variable length and position, as it was with two dots.

These results led to the next set of experiments. Both sets of data are being written up by the principal investigator in a paper on the effect of the orthogonal dimension in macrolocalization. (This work was delayed by the need to get a complete set of data on a second observer. Those measurements have recently been completed.)

J. Effect of Orthogonal Position on Macrolocalization Accuracy

Given the excellence of the subject's performance in the experiments described above, we decided to determine the extent to which he could ignore variation in the position of the stimulus in the direction orthogonal to the one of interest. For simplicity, we will refer to the direction along which the subject is to judge distance as the principal orientation, and the direction orthogonal to the principal orientation as the orthogonal orientation. In this experiment, we used two dots so that the stimulus itself did not specify the orthogonal orientation. The distance between the dots in the principal direction was one of 14 values, 7 less than the average and 7 greater than the average distance. The subject's task was to indicate whether the distance between the dots in the principal

direction was greater or less than the average. Macrolocalization accuracy was measured by the method of constant stimuli as in previous experiments.

In the control experiment, the dots were simply aligned along the principal orientation (as they were in the previous experiments), whereas in the test experiments, one dot was also randomly offset relative to the other along the orthogonal orientation. The extent of the orthogonal displacement varied randomly from trial to trial in the range from 0 to approximately 20 times the maximum test Δs in the principal orientation. Thus, the variation in position in the orthogonal direction was much larger than the variation in position in the principal direction. The subject's task was to ignore the variation in the orthogonal direction and to determine whether the distance between the objects in the principal direction was greater or less than the average that he had seen on previous trials.

Data were collected for both test and control conditions, in interleaved runs, at 7 orientations (obtained with a dove prism): 0, 15, 30, 45, 60, 75 and 90 degrees. A circular surround and darkened room were again used to eliminate any other cues to orientation.

Data for the two observers are shown in Figs. 7 and 8. We found that subjects are remarkably good at ignoring the effects of the orthogonal displacement. The ratio of localization threshold with and without orthogonal displacement averaged 1.49 for one observer, and 2.57 for the other. Furthermore, in neither the centered nor the random-orthogonal-displacement condition was there any systematic variation in sensitivity with orientation. Thus, there was also no systematic variation in the effect of the orthogonal displacement with orientation. Subjects could determine the principal direction with approximately equal accuracy at all orientations measured.

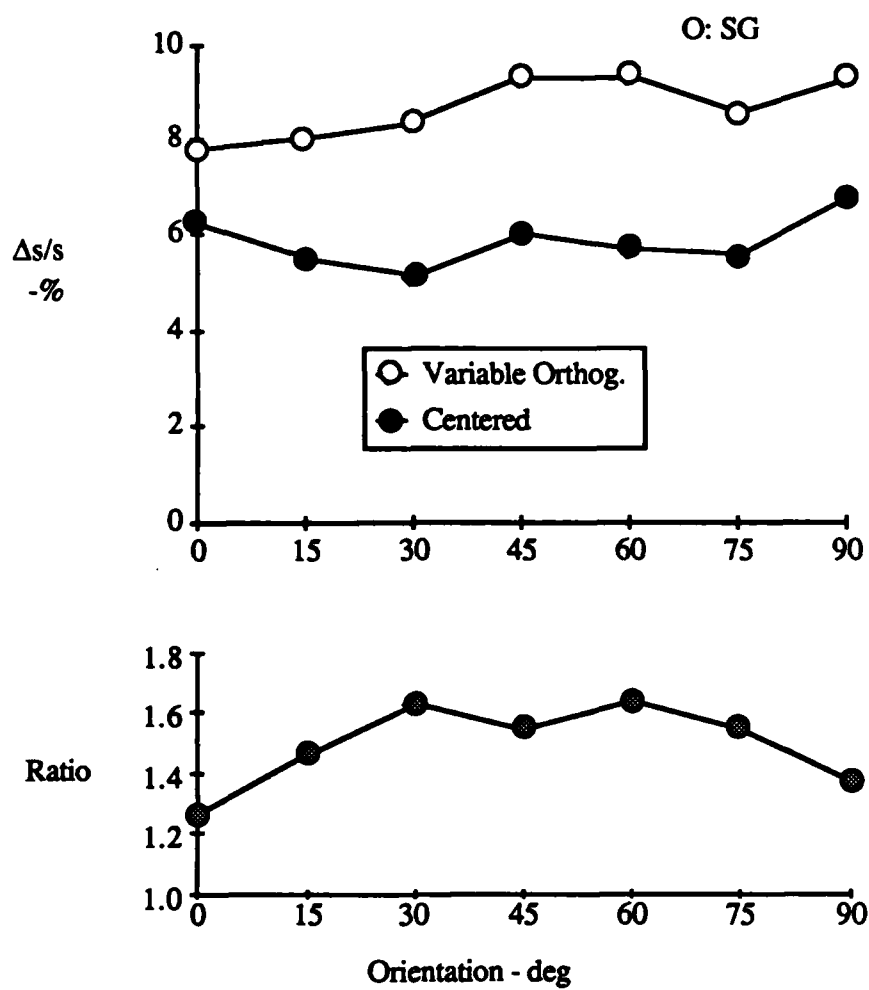


Fig. 7

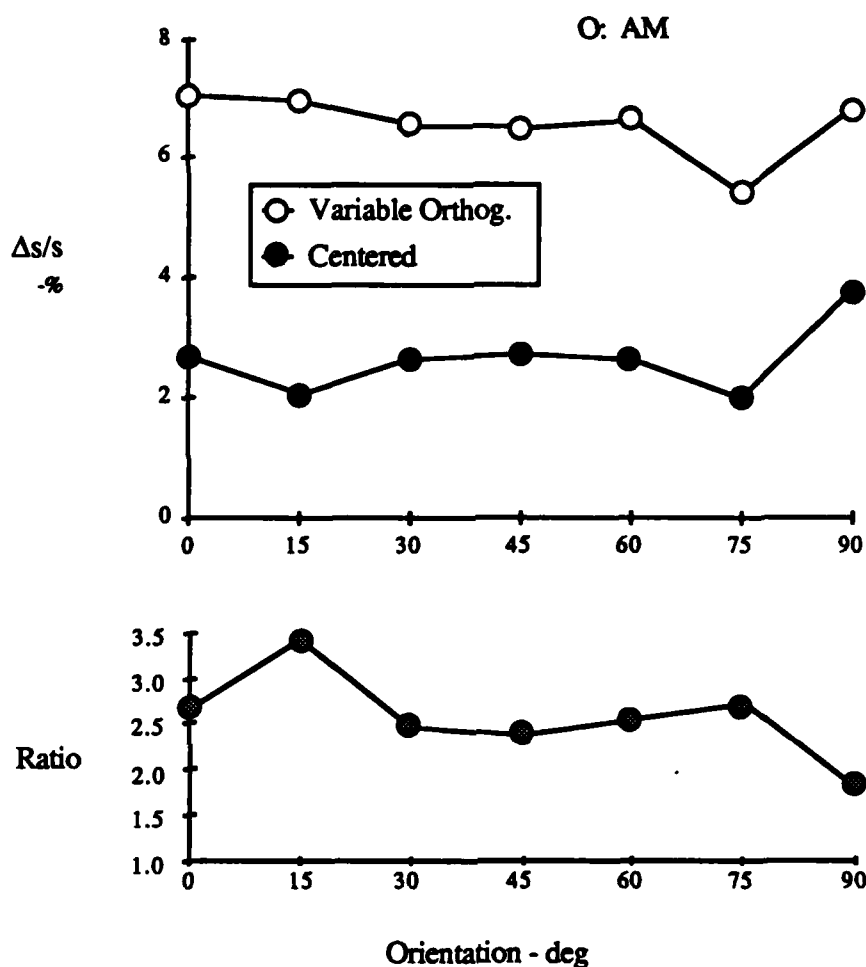


Fig. 8

We concluded that the macrolocalization system is sensitive to orientation, but has no preferred orientation. The ability to ignore variation of position in the orthogonal dimension accounts for the insensitivity of the macrolocalization system to the orthogonal extent of objects, and thus begins to explain how this system can achieve such a high degree of accuracy with spatially extended objects.

These data also fit in well with the type of model of spatial localization that was required to account for the previous results. We postulate that localization of widely separated objects does not occur in the retinotopic representation that has been extensively modeled in terms of units that are coarsely tuned to orientation and spatial frequency. Rather it occurs at a subsequent stage in which the representation is more symbolic. We hypothesize that a primary function of this stage of visual processing is to introduce fundamental invariances, such as size constancy (see below) and

relative, rather than absolute retinal, position.

K. Frequency Discrimination, Channels, and Size Constancy

The experiments reported above provide strong evidence that relative spatial localization of widely separated objects cannot be accounted for in the primary representation (which consists of spatial frequency and orientation-selective units), but requires significant subsequent processing. This subsequent stage of basic spatial processing is also required to account for the results of experiments recently performed on the relationship between size-constancy and frequency-channel models of frequency discrimination.

Current models of frequency discrimination postulate that the discrimination is based directly on the responses of units in the primary representation that are tuned to specific retinal spatial frequencies. We tested these models in the following manner. Rather than using a single display screen, we used two displays and presented the gratings to be compared at different distances from the observer, as shown in Fig. 9.

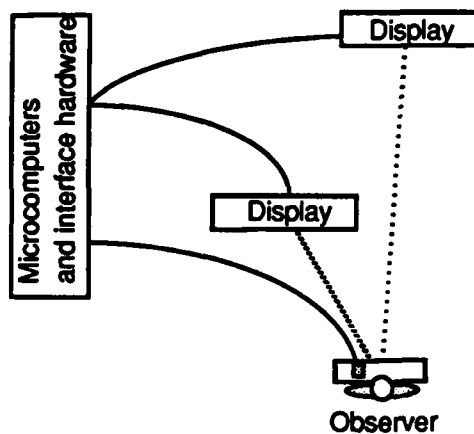


Fig. 9

Under these conditions, observers do not match the retinal spatial frequencies, but rather make an approximate match of the objective spatial frequencies, that is, they attempt to match the properties of the stimuli, not of their retinal images. This simply is another way of saying that the well-known phenomenon of size constancy holds in the laboratory with sine wave gratings, just as it does in more complex environments. However, these experiments set the stage for the important finding. We attempted to teach observers to compare the retinal spatial frequencies of the stimuli, ignoring the depth information. There was no evidence that they could make this judgment: Comparison was always made on the basis of the objective frequencies. Observers performed no better when the retinal spatial frequencies provided directly useful information than when they did not. It appears that observers do not have direct access to the retinal spatial frequency information. Instead, the retinal frequency information is transformed into estimates of objective frequency at a site prior to the stage at which the observer makes his comparison. If this result is true in the

equidistant case as well, frequency discrimination data always include the effects of that transformation. Therefore, our finding may have serious ramifications for current models of frequency discrimination.

A report of the research done to date on this subject was presented at the OSA meetings in Washington, D.C. in October of this year. A paper reporting these findings was also recently submitted to Journal of the Optical Society of America.

IV. Publications (sponsored by this contract)

"Independence of Orientation and Size in Spatial Discriminations," with D. Regan, *J. Opt. Soc. Am.* 73, 1691-1694 (1983).

"Frequency Discrimination, Channels and Size Constancy," submitted to *J. Opt. Soc. Am.*, Sept. 1985.

"Spatial Localization with Large and Small Object Separations" to be submitted to *J. Opt. Soc. Am.*

"Separate Channels for the Analysis of Form and Location," to be submitted to *J. Opt. Soc. Am.*

"Orientation-Selectivity in Relative Spatial Localization," in preparation for Vision Research.

V. Professional Personnel Associated with this Research Effort

Christina A. Burbeck, Senior Research Psychologist, Sensory Sciences Research Laboratory, SRI International, Principal Investigator.

David Regan, I. W. Killam Research Professor in Physiology and Ophthalmology, Dalhousie University, Halifax, Nova Scotia, collaborator during first year of research effort.

VI. Interactions - spoken papers (on subjects covered by this contract)

"Temporal Factors in Color Discrimination," with D. Regan, Association for Research in Vision and Ophthalmology meeting, May, 1983.

"Second Thoughts About Channels," Theme paper for "Models of Visual Processing" Workshop, sponsored by the Air Force Office of Scientific Research, May 8, 1983.

"Relative Spatial Localization: A Fundamental Visual Process," videotape shown at Annual Review of Air Force Sponsored Basic Research in Visual Information Processing, May, 1984.

"Separate Channels for the Analysis of Form and Location," Association for Research in Vision and Ophthalmology meeting, May, 1985.

"Frequency Discrimination, Channels, and Size Constancy," Optical Society of America meeting, October, 1985.

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