The Study of Context Effects in Medical Image Contrast Enhancement Assessment via a Binocular Ganzfeld

TR92-001

January, 1992

Derek T. Puff

The University of North Carolina at Chapel Hill
Department of Computer Science
CB#3175, Sitterson Hall
Chapel Hill, NC 27599-3175

UNC is an Equal Opportunity/Affirmative Action Institution.

THE STUDY OF CONTEXT EFFECTS IN MEDICAL IMAGE CONTRAST ENHANCEMENT ASSESSMENT VIA A BINOCULAR GANZFELD.

Derek T. Puff

A Thesis submitted to the faculty of The University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in the Department of Biomedical Engineering.

Chapel Hill

1991

Approved by:

Stephen M. Pizer ______ Advisor

Christina A. Burbeck ______ Reader

______ Reader

© 1991
Derek Thomas Puff
ALL RIGHTS RESERVED

DEREK T. PUFF. The Study of Context Effects in Medical Image Contrast Enhancement Assessment via a Binocular Ganzfeld.

ABSTRACT

The context in which local structures in a medical image are viewed has an impact on a human observer's ability to localize, identify, and characterize those structures and as such is an important visual feature for incorporation in models and methods in medical image enhancement and display. Medical image contrast enhancement methods specify a transformation by which acquired image values are mapped to the display in a way that increases the contrast between relevant anatomical structures and the background or adjacent structures. These contrast enhancement techniques may eventually be evaluated with computer methods that predict the performance for an array of modeled visual tasks. The model utilized to define the visual mechanisms required in these tasks must incorporate a knowledge about particular influences of context on localized detection and discrimination. In pursuit of this understanding, several context experiments were conducted with a binocular ganzfeld. The physical characteristics of the ganzfeld, which allows presentation of greyscale images without the influence of extraneous surrounding contextual structures or borders present under normal display conditions, and the results of those studies, are presented.

ACKNOWLEDGMENTS

I wish to thank my three advisors, Stephen Pizer, Christina Burbeck, and Benjamin Tsui, whose loyal support of my pursuit of competence amidst bouts of graduate clumsiness was as important to me at times as their theoretical contributions to my education. In addition, Gene Johnston has been a constant source of stability and advice. Victor Klymenko spent many late evenings with me designing some of the initial experiments. Thanks to Keith Muller and Doug Taylor for lessons in the theory and implementation of the statistics in this thesis. Thanks to Brad Hemminger, Shava Averett, and Stan Dempsey for the computer and electronic support that I often selfishly demanded. I finally wish to recognize and thank my mother; her inspirational strength and loving support fostered my determination and enabled my endurance .

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The task of detection and discrimination of relevant structures and abnormalities in a medical image incorporates inherent visual processes. In order to optimize this perception and ultimate diagnosis, the methods by which medical images are enhanced, displayed and evaluated must include consideration of the perceiving characteristics of the human visual system.

Medical image contrast enhancement methods allow the manipulation of acquired digital information in a way that improves the contrast between relevant structures and the background or other adjacent structures. Contrast enhancement can calculate the value for each location in the displayed image based on a computation of the structural content of the surrounding context and theoretically provide an enhancement of the contrast of local structures relative to their surround. The determination of the proper contextual region surrounding each pixel in which to calculate a local enhancement must be made with both a computation of the location and characteristics of surrounding structures and an implemented understanding of context which makes predictions about the inclusion of surrounding structures in this region.

Contrast enhancement methods are typically assessed with human observer studies, which measure the performance of the observer in carrying out the tasks involved in the interpretation of images. However, methods are being developed which compute descriptions about local contrast and detectability with algorithms modelled after visual operations. The results of this analysis provide an assessment of the image, based on the performance on computed tasks, that theoretically reflects the inherent capabilities and limitations of a human observer. A visual model for the perception of object form is required as a foundation for such a task description, and an understanding of context is a particularly important parameter in this development.

Studies have indeed proven that the context in which objects are viewed will often have a significant effect on the way in which those objects are perceived; their detection, assigned identity, and characterization may be highly dependent on or even dictated by the nature, identity and organization of adjacent edges and structures. Errors in brightness perception related to the arrangement of surrounding objects have been demonstrated psychophysically and further proven to extend to clinical assessments.

It is therefore a relevant endeavor in the development of a visual model for utilization in medical image enhancement assessment to attempt to characterize the effects of context on contrast discrimination. The ganzfeld presented here is a display device that consists of a large viewing screen in which the edges of the screen are positioned peripherally such that the binocularly-viewed surface virtually encompasses the observer's field of vision. Greyscale images can be electronically presented with this system to enable the study of contrast detection or discrimination within a number of imposed and entirely controlled surround conditions. The experiments which will be reported utilized this ganzfeld to study the discrimination of a target in the presence of surrounding closed contours of various diameters, shapes, and contrasts.

The goal of medical image enhancement is to improve the characterization and interpretation of information in the image. The studies reported here attempted to foster an understanding of the properties of local context and contribute to the modelling of visual performance in medical imaging.

II. MEDICAL IMAGING SYSTEM

The system involved in interpretation and perception of information in a medical image consists of a number of ordered components.[1] In this sequence of the digital construction and display of a medical image, the array of intensity values reflecting the differential response characteristics of anatomical structures to the imposed imaging technology are mapped to a digital display device possessing a limited resolution and range of display intensities. In the final stages, optical and neural components of the observer's visual system operate on the displayed values to generate perceived brightnesses in the observer's brain.

A. ACQUISITION

The initial energy source, which is characteristic of the imaging modality applied, is imparted to the human anatomy. When the inducing energy from the imaging source encounters these structures, it interacts differentially with the many structures in the body because of differences in the absorption and density properties of each of these structures. Thus the values at each point in the image, recorded by the imaging system and ultimately the display device, reflect information about the transmission of the particular physical parameter utilized by the imaging modality. In the case of radiography, the distribution of

---

[1] C.C. Jaffe. Medical Imaging, Vision, and Visual Psychophysics, Medical Radiography and Photography, vol 60, no. 1 (Eastman Kodak Company,1984), 6.

intensity variations across the image represent the x-ray attenuation properties of the corresponding anatomy.[2]

B. ENHANCEMENT AND DISPLAY

The display process transmits the acquired intensity values to the viewer via an optical array of light. In imaging systems with a digital display format, once this acquired information is represented digitally, the raw intensity values are mapped to the display device via some transformation.

At this stage, there exists the opportunity to impose an explicit transformation in this assignment to grey levels, contrast enhancement, that conforms to some of the properties of the human visual system and effectively "resamples" or differentially maps the recorded intensities to enhance properties of the displayed image.[3]

C. VISUAL PERCEPTION

The chosen display intensities undergo further transformations in the retina and brain of the observer such that the final representation of the image exists as perceived brightness. In the eye, retinal receptors are organized into circular or elliptical regions which contribute via a weighted distribution to the receptive fields of more cortical visual neurons. The receptive fields are responsive to specific stimulus orientations, gradients, widths, and temporal characteristics, and multiple concentric receptive fields are positioned at each image

---

[2] R.H. Morgan, "Visual Perception In Fluoroscopy and Radiography," Radiology 86 (March,1966): 403-416.

[3] S.M. Pizer, "Psychovisual Issues In the Display Of Medical Images," K.H. Hoehne, ed., Pictorial Information Systems In Medicine (Berlin: Springer-Verlag, 1985), 211-234.

point allowing resolution at multiple scales.[4] Properties of receptive fields cause them to respond characteristically to object features, particularly edges. Perceived objects are thought to be constructed by the integration or combination of these features from the image.

Edges are prominent in the perception of objects by the human visual system,[5] and it appears that brightness judgments for structures made in the interpretation of medical images are influenced by the stucture's size and edge characteristics. Furthermore, brightness judgments are characteristically relative, and are predictably influenced by the surrounding luminance values that make up the local context in the image.

This delineation of the stages of medical imaging acquisition, display, and perception emphasizes the vital role of visual mechanisms in that process. In particular, context will be shown to be an important visual parameter, and contrast enhancement methods and their accompanying methods of assessment must incorporate an understanding of the effects of spatial context on brightness and form perception.

---

[4] S.M. Pizer and B.M. ter Haar Romeny, "Fundamental Properties Of Medical Image Perception," Journal of Digital Imaging, vol. 4, no. 1 (February 1991): 1-20.

[5] A. Gilchrist, S. Delman, and A. Jacobsen, "The Classification and Integration Of Edges As Critical To the Perception Of Reflectance and Ilumination," Perception and Psychophysics, vol. 33, no. 5 (1983): 425-436.

III. CONTRAST ENHANCEMENT METHODS

Contrast enhancement methods accentuate or emphasize particular objects or structures in an image by mapping the intensity values in the acquired image to the grey levels in the display by a predetermined transformation that amplifies the contrast between structures. The methods compensate for the nonlinearity in brightness perception of the human visual system. They are not designed to increase or supplement the inherent structural information in the image, but simply improve the contrast and theoretically enhance particular characteristics.[1]

An enormous range of intensity information is contained within an image. In a radiograph, the radiation attenuation in the mediastinum is many times greater than in the lungs. Histogram-based contrast enhancement methods aim to effectively represent, by distributing uniformly, information from all of these recorded intensities in the limited intensity range of the display grey scale.[2] Other methods attempt to selectively enhance specific features in the image.

There are two broad categories of enhancement methods. Global methods perform the same operation on each pixel in the image. Adaptive methods perform an enhancement by choosing a value for

---

[1] A.K. Jain, Fundamentals Of Digital Image Processing (Englewood Cliffs, NJ: Prentice Hall, 1989), 233.

[2] G.A. Johnson, N. Danieley, and C.E. Ravin, "Processing Alternatives For Digital Chest Imaging," Radiologic Clinics of North America, vol. 23, no. 2 (June 1985): 335-340.

each position in the image based on the surrounding values in a specified contextual region, and are further distinguished based on the way that this contextual region is chosen.[3,4]

A. GLOBAL METHODS

Global methods of contrast enhancement apply a single transformation to the image that is independent of spatial coordinates. They are easily implemented, but do not account for context in the image.

1. Intensity Windowing. Windowing is an interactive method in which the user selects a specified subrange of the recorded intensities to be displayed. Because a smaller range of the recorded intensities is displayed, greater contrast is exhibited between the values in the subrange. However, values above and below the selected region are mapped to the highest and lowest display values, respectively, and the structures described by intensity values outside the windowed region are displayed with no contrast.

2. Histogram Equalization. The histogram of an image plots the frequency of occurrence of each grey level in the image. Histogram equalization is a remapping by which the histogram of the image is flattened so that the pixels in the image are uniformly distributed among the available grey levels. This remapping devotes a proportionally large number of grey levels to intensity values with

---

[3] B. Plessis, M. Goldberg, R. Dillon, J. Tombaugh, J. Robertson, G. Belanger, and N. Hickey, "Context-Dependent Enhancements For Radiological Images," Journal of Digital Imaging, vol. 2, no. 2 (May 1989): 114-122.

[4] R. Cromartie and S.M. Pizer, "Adaptive Contrast Enhancement Of Medical Images," Supplement to the Proceedings of the North Sea Conference on Biomedical Engineering, (Nov. 1990).

high frequencies of occurrence. Regions of the image with small yet frequent and perceptually crucial intensity variations or gradients are thus rendered with greater contrast.

3. Histogram hyperbolization. Histogram hyperbolization calculates a histogram for the displayed intensities that possesses a hyperbolic shape. Because human brightness perception is logarithmic, a histogram that is shaped as a hyperbola should produce displayed intensity differences which are perceptually equivalent.[5] However, as some have pointed out, this method is equivalent to histogram equalization with a perceptually-linearized display device. Furthermore, hyperbolization does not account for the fact that perceived brightness is a function of intensity variations in the surrounding context as well as absolute luminance.[6]

B. ADAPTIVE METHODS

Adaptive contrast enhancement methods aim to optimize contrast in all regions of the image by performing adaptive or local operations relative to local context in determining the enhancement assignment for each pixel. The region surrounding the pixel in question that is used as its context is called its contextual region, and can be defined in size and shape in a number of ways. Non-structural enhancement methods choose for the computation of the enhancement applied to a particular pixel a contextual region shape and size that are predetermined and uniformly applied at each pixel.

---

[5] W. Frei, "Image Enhancement By Histogram Hyperbolization," Computer Graphics and Image Processing, vol. 6 (1977): 286-294.

[6] R. Cromartie and S.M. Pizer, "Adaptive Contrast Enhancement Of Medical Images," 2.

Structural enhancement methods, on the other hand, take into account the location and edge strengths of structures in the region surrounding the image to determine the shape of the contextual region utilized for that pixel in the subsequent enhancement.

1. NON-STRUCTURAL METHODS

a. Unsharp Masking. Modelled after photographic unsharp masking procedures,[7] the digital technique of unsharp masking subtracts a low-pass, or blurred, version of the image from the original image. The image that results from this subtraction, which contains the detailed information from the original image, is then amplified and added back to the blurred image. The image that results from this addition emphasizes high-frequency features in the image.

b. Adaptive Filtration. Adaptive filtration involves the selective enhancement of specific features of the image. By amplifying high spatial frequencies in the image, for instance, edges can be enhanced.[8]

c. Adaptive Histogram Equalization. Adaptive histogram equalization[9] computes a histogram for the contextual region of each pixel under consideration. The contextual region is typically square, but may vary in size or shape (the contributions of pixels in the region

---

[7] J.A. Sorensen, L.T. Niklason, and J.A. Nelson, "Photographic Unsharp Masking In Chest Radiography," Investigative Radiology, vol.16 (July-Aug 1981): 281-288.

[8] T. Peli and J.S. Lim, "Adaptive Filtering For Image Enhancement," Optical Engineering, vol. 21, no. 1 (1982): 108-112.

[9] S.M. Pizer, "An Automatic Intensity Mapping For the Display Of CT Scans and Other Images," Medical Image Processing: Proceedings of the VIIth International Meeting on Information Processing in Medical Imaging, Stanford University (1981): 276-309.

might be weighted, for instance).[10] In this way, contrasts at many different grey levels and all positions in the image are perceivable.

In addition, "grey level-dependent processing" can capitalize on an *a priori* knowledge of the typical shape of the histogram; raw intensity values may be mapped by one of several transformations based on the hypothesized characterization of a pixel as lying within a structural region known to be described by intensity values of a particular region of the histogram.[11,12]

d. Clipping. Noise in a histogram-equalized image often becomes noticeable in uniform regions processed by adaptive histogram equalization. High peaks in the histogram of the image are caused by large uniform regions since lots of pixels in a uniform region possess a single, or similar, values. For a histogram with a large peak, the narrow band of intensity values to which the peak corresponds will be mapped to a broad range of display values. This mapping may in fact be so broad that the enhanced noise is objectionable. A solution is to "clip" the histogram at a particular height so as to limit the contrast. This clipping is equivalent to limiting the slope of the cumulative histogram. The clipped pixels must then be reallocated; this

---

[10] S.M. Pizer, E.P. Amburn, J.D. Austin, R. Cromartie, A. Geselowitz, B. ter Haar Romeny, J.B. Zimmerman, K. Zuiderveld, "Adaptive Histogram Equalization and Its Variations," Computer Vision, Graphics, and Image Processing, vol. 39 (1987): 355-368.

[11] R.H. Sherrier and G.A. Johnson, "Regionally Adaptive Histogram Equalization Of the Chest," *IEEE Transactions on Medical Imaging*, vol. MI-6, no. 1 (March 1987): 1-7.

[12] H.P. McAdams, G.A. Johnson, S.A. Suddarth, and C.E. Ravin, "Histogram-directed Processing Of Digitial Chest Images," Investigative Radiology, vol. 21 (March 1986): 253-259.

reallocation is most efficiently and effectively done by uniformly redistributing those pixels across all intensity values in the image.[13]

2. STRUCTURAL METHODS

Methods of contrast enhancement may employ a contextual region for the calculation of the histogram surrounding a pixel that is shaped to conform to local object boundaries. To accomplish this, the contextual region may be constructed by an anisotropic diffusion process[14] in which the diffusion into the region surrounding the pixel of interest would at some distance (which could be different at each radial position) be limited by an edge possessing sufficient "strength."

When the unsharp image utilized in the unsharp masking enhancement technique is generated by blurring the image in a way dictated by this diffusion process, low contrast edges are blurred and the resulting combined image exhibits enhanced edges and other high frequency information. Alternatively, diffusive histogram equalization utilizes this edge-limited blurring process to calculate the contextual region for each pixel. A value is diffused anisotropically from each pixel as dictated by the edge strengths that it encounters in the original image, and the contextual region is delineated by the distances of diffusion surrounding the pixel after some length of time. The resultant histogram for each pixel is thus derived from a variable region that reflects the presence and contextual strength of structures

---

[13] S.M. Pizer, *et.al.*, "Adaptive Histogram Equalization and Its Variations," 363-365.

[14] P. Perona, and J. Malik, "Scale-Space and Edge Detection Using Anisotropic Diffusion," Report No. UCB/CSD 88/483, Computer Science Division (EECS) University of California, Berkely, California (December 1988).

surrounding the pixel in question.[15] Diffusive histogram equalization effectively enhances the contrast of features in the image without modifying already sharp edges.

C. EFFECTIVENESS

A number of clinical studies have been conducted which relate the effectiveness of several of these methods. A photographic unsharp masking procedure was shown to enhance detection of nodules in chest radiographs,[16] and likewise improved detection for square test patterns embedded in noise.[17] Adaptive filtration applied to a series of digitized chest radiographs improved detection of lung nodules.[18] Recently, in a study in which contrast-limited adaptive histogram equalization preceded by anisotropic unsharp masking was applied to radiation portal films, the task of portal and simulator film alignment was performed more accurately with enhanced films.[19] The structural methods of contrast enhancement hold particular promise for clinical efficacy because of their ability to incorporate structural information

---

[15] R. Cromartie and S.M. Pizer, "Adaptive Contrast Enhancement Of Medical Images," 5.

[16] J.D. Armstrong, J.A. Sorensen, J.A. Nelson, I. Tocino, P.D. Lester, J.O. Janes, L.T. Niklason, and W. Stanish, "Clinical Evaluation Of Unsharp Masking and Slit Scanning Techniques In Chest Radiography," Radiology, vol. 147 (May 1983): 351-356.

[17] L.D. Loo, Doi, K, and C.E. Metz, "Investigation Of Basic Imaging Properties In Digital Radiography. 4. Effects of Unsharp Masking on the Detectability of Simple Patterns," Medical Physics, vol. 12, no. 2 (Mar-April 1985): 209-214.

[18] R.H. Sherrier, C. Chiles, W.E. Wilkinson, G.A. Johnson, and C.E. Ravin, "Effects Of Image Processing On Nodule Detection Rates In Digitized Chest Radiographs: ROC Study Of Observer Performance," Radiology, vol.166 (1988): 447-450.

[19] J. Rosenman, C.A. Roe, R. Cromartie, K.E. Muller, and S.M. Pizer, "Portal Film Enhancement: Technique and Clinical Utility," (to be submitted) International Journal of Radiation Oncology, Biology, and Physics. 1991.

from the surrounding context; these methods are currently being developed and implemented.

The following section on contrast enhancement assessment further addresses how the methods evaluated clinically in these examples might otherwise be assessed.

IV. CONTRAST ENHANCEMENT ASSESSMENT

Contrast enhancement methods have traditionally been evaluated by measuring the clinical diagnostic accuracy of experienced readers with enhanced images or by employing some approximation of the clinical task which involves human observers. This assessment of the accuracy of human performance is typically accomplished via the science of ROC analysis. However, some of the shortcomings of this approach have prompted attempts to devise computer methods for calculating measures of image quality. Image assessment methods which employ calculations modeled after visual processes are particularly attractive in this regard since they theoretically make an evaluation of the image that would be characteristic of human performance.

A. OBSERVER STUDIES

ROC (receiver operator characteristics) methods analyze the performance of an observer as he/she varies the decision threshold adopted in a viewing or diagnostic task. In a detection, discrimination, or identification task, the sensitivity is the fraction of correct identifications over the total number of cases in which the indicator is present (total number of actual positives). Similarly, specificity is the fraction of correct rejections over the total number of cases in which the indicator was absent (the total number of actual negatives). The ROC curve plots sensitivity (or the "true positive fraction") as a function of 1/specificity (the "true negative fraction"). The shape of the ROC curve reflects the compromises an observer makes between correctly indicating the presence of some indicator and avoiding unnecessary "false alarms." ROC analysis provides a description of detectability that is independent of the prevalence of the particular indicator and furthermore forces the decision threshold to vary so that different procedures might be compared.[1] These methods can be applied in the subjective comparison of techniques; performance and accuracy of human observers can be used to differentiate and evaluate methods. However, ROC methods require skilled observers whose time is limited and costly.

B. IMAGE QUANTIFICATION

A measure of image quality can be derived from the quantification of physical characteristics of the image. Characteristics of the image, such as the signal-to-noise ratio, resolution, or contrast, can be combined into a formula, which, when calculated for a particular image, produces a number that represents a measure of image quality. However, it is often questionable which characteristics ought to contribute to such a function and how heavily each should be weighted. It seems preferable that such a calculation be based on image characteristics that are important to human performance.

C. IDEAL OBSERVER ASSESSMENTS

Another approach to image quality assessment is to utilize all of the capabilities of the computer to make the detection and

---

[1] C. Metz, "Basic Principles Of ROC Analysis," Seminars in Nuclear Medicaine, vol. 8, no. 4 (Oct. 1978): 283-298.

characterization decisions of an "ideal observer." The ideal observer is a mathematical construct that operates, using all available and *a priori* information about the image, to "minimize the overall probability of making a decision error."[2] However, an ideal observer algorithm may have access to information that the human does not. Conversely, the ideal observer calculations may not be able to implement some of the remarkable characteristics and capabilities possessed by the human visual system in the representation of global image relationships.

D. VISUAL TASK-BASED METHODS

If the human task of medical image evaluation can be decomposed into a set of well-defined visual tasks, and further, if a visual model can be developed which makes predictions about the fundamental perceptual mechanisms involved in those tasks, then there exists the promise that methods of contrast enhancement assessment might calculate a determination of the quality of an image based on the performance of algorithms which incorporate modeled visual mechanisms and conduct these tasks in an image.

These methods might compute estimates about the shape of objects, or interobject distances or contrasts that were produced by a given contrast enhancement method. Cromartie,[3] in his upcoming doctoral dissertation, will outline a number of visual tasks that might be performed in the visual interpretation of form and structure in an image.

---

[2] K.J. Myers and H.H. Barrett, "Addition Of a Channel Mechanism To the Ideal-Observer Model," Journal of the Optical Society of America, vol. 4, no. 12 (Dec. 1987): 2447-2457.

[3] R. Cromartie, personal communication. May, 1991.

The calculations of such an enhancement assessment thus depend heavily on the particular visual model chosen as the basis for the prediction of visual mechanisms. The sections that follow describe a visual model that offers predictions and descriptions about the perception of objects that can be implemented for these defined assessment tasks.

V. MULTISCALE MEDIAL MODEL

A. DESCRIPTION

Traditional theories of object description have applied boundary contour tracking mechanisms in the characterization of shape as the closed contour comprised of edge components. Such approaches have been fruitful for defining a boundary which functions as a delimiter in perceptual "filling-in" processes,[1,2] or as the structural basis for the segmentation of the figure from its background.[3]

The multiscale medial model of visual object formation recently developed by Stephen Pizer and his colleagues at the University of North Carolina-Chapel Hill provides an alternative mechanism of shape definition that encompasses both a medial axis description of the position of the object and the location of its edges, and multiscale properties for invariant recognition of the object at any spatial size. A model with these characteristics can, by virtue of its more global description of shape, overcome the difficulties encountered by boundary curvature models by offering a representation of object shape invariant of size and orientation, and responsive to overall shape as

---

[1] S. Grossberg and E. Mingolla, "Neural Dynamics Of Perceptual Grouping: Textures, Boundaries, and Emergent Segmentations," Perception and Psychophysics, vol. 38 (1985): 141-171.

[2] S. Grossberg and D. Todorovic, "Neural Dynamics Of 1-D and 2-D Brightness Perception: A Unified Model Of Classical and Recent Phenomena," Perception and Psychophysics, vol. 43 (1988): 241-277.

[3] P.K. Kienker, T.J. Sejnowski, G.E. Hinton, and L.E. Schumacher, "Separating Figure From Ground With a Parallel Network," Perception, vol. 15 (1986): 197-216.

well as more localized edge fluctuations. This model is presented here essentially as described by Pizer, Coggins, and Burbeck.[4]

An integral property of the multiscale medial model is its medial representation of the position and corresponding boundary of the object. The medial axis is the series of connected points which are defined by the locus of the circle which tangentially and bilaterally engages the edges of the object at a given position along the object (Figure 5.1).

Blum[5] first advanced medial principles in a description of global brain function. Specifically, he posited the existence of propagating circular waves, which formed a medial representation of the distance to the edge of the shape or volume via intersections of multiple waves. Marr and Nishihara[6] developed a theory for the perception of natural objects which includes several processing stages in which the elements of the structure are defined by cylinders which are in turn inherently defined by a medial axis description. Leyton[7] attempts a more unified explanation of this medial representation as a plausible grouping approach in his exposition of the perceptual organization of vision.

A similar approach to shape definition, which incorporates peaks and ridges as the medial representation of objectivity, has been

---

[4] S.M. Pizer, J.M. Coggins, and C.A. Burbeck, "Formation Of Image Objects In Human Vision, " CAR Proceedings, (Berlin: Springer-Verlag, 1991).

[5] H. Blum, "A New Model Of Global Brain Function," Perspectives in Biology and Medicine, vol. 10 (1967): 381-407.

[6] D. Marr and H.K. Nishihara, "Representation and Recognition Of the Spatial Organization Of Three-Dimensional Shapes," Proceedings of the Royal Society of London, vol. B200 (1978): 169-294.

[7] M. Leyton, "Perceptual Organization As Nested Control," Biological Cybernetics, vol. 51 (1984): 141-153.

applied to image processing techniques. Descriptions of shapes in an image can be constructed by detecting peaks and ridges in the difference of a low-pass (DOLP) transform. Linking adjacent peaks from different bandpass images gives a multiple resolution description of shape.[8]

The representation of objects at multiple scales is an essential property for maintenance of perceptual invariance and flexibility in the level of focus. The model possesses neurons which have different receptive field sizes, and the receptive field size effectively defines the scale at which the neuron responds. The notion of the existence of multiple channels for encoding scale was first made possible by the physiological discovery, in the cat cortex, of linearly operating neurons selectively tuned for narrow bands of spatial frequency.[9]

Recently, Koenderink has argued the existence of a family of multiscale receptive fields which are local operators of different symmetries and sizes.[10] Mathematically, the receptive fields are described as "linear combinations of derivatives of a Gaussian." The multiscale medial model incorporates these receptive fields. Furthermore, it appears that physiological evidence supports the hypothesis, derived from such a mathematical description, of the existence of receptive fields shaped like combinations of a Gaussian.

---

[8] J.L. Crowley and A.C. Parker, "A Representation For Shape Based On Peaks and Rdges In the Difference Of a Low-pass Transform," IEEE Transactions, PAMI, vol. 6, no. 2 (1984): 156-170.

[9] F.W. Campbell, G.F. Cooper, and C. Enroth-Cugell, "The Spatial Selectivity Of the Visual Cells Of the Cat," Journal of Physiology, vol.203 (1969): 223-235.

[10] J.J. Koenderink, "The Brain a Geometry Engine, Psychol. Research, (1990).

Young[11] indeed describes the shape of measured receptive fields in the primate cortex as the sum of a Gaussian distribution and its second derivatives.

The collective properties of a multiscale medial representation of shape have engendered a visual model with the following operational description. The model generates a representation of the responses of neurons, each identified by a position derived from the location of its receptive field, a scale which represents the size of its receptive field, and a geometric property which is a description of the existence or extent of, for example, an edge or corner, and which is derived from the characteristic response of one of a family of receptive fields. Families of neurons signalling orientation and scale contribute to the generation of a response which possesses both magnitude, which reflects the extent of bilateral edge engagement, and direction (of the medial axis) information at the particular scale of the neuron family. "End-stopped cell pairs" represent the ends of the medial axis. At any position along the axis, information regarding the scale, which represents the distance of the boundary, and the direction of the axis, can be acquired.

B. IMPORTANCE OF CONTEXT

The model yields a "scale trace" which is the peak scale response for each x,y position in the image. The medial axis is derived from a process of ridge-finding in scale space. In making this calculation, the model, for each position in a visual scene, selects out of scale space

[11] R.A. Young, "The Gaussian Derivative Model For Spatial Vision: I. Retinal Mechanisms," Spatial Vision, vol. 2 (1987): 273-293.

special distances which correspond to edges (Figure 5.2). These edges may belong to the object to which the point in question belongs or they may be part of adjacent structures. The context in the scene thus determines the scales over which the representation of the object is computed. It becomes very important then, in formulating visual models which include scale, and in particular a multiscale model of perception, to understand how context influences local perceptual judgments. It will be necessary to measure the range over which contextual factors can exert their effects and characterize the properties of contextual influences.

VI. CONTEXT STUDIES

Several approaches have provided psychophysical data characterizing the contextual influences on local detection and discrimination. In principle, Weber's law predicts that the just noticeable difference between intensities is proportional to the reference intensity. However, brightness perception for a point in the visual scene reflects the integration of responses from a number of receptors.[1] In particular, contours, or areas of sharp contrast, often influence the perceived brightness of uniform regions of luminance.

The influence of contours can extend to adjacent regions by the lateral inhibition of photoreceptors at the boundary between regions. For instance, retinal receptors receiving strong illumination will inhibit neighboring receptors, and when the neighboring receptors lie on the opposite side of a border in an adjacent region of lower luminance, the already dimly-illuminated receptors can be further inhibited.[2] The Craik-O'Brien illusion demonstrates this phenomenon: luminance cusps at the edge between identical uniform backgrounds cause a significant perceptual difference in the brightness of the two regions.[3] Land[4] has shown in color vision that the

---

[1] D. Jameson, and L.M. Hurvich, "Complexities Of Perceived Brightness," Science, vol.133 (1961): 74-179.

[2] F. Ratliff, "Contour and Contrast," Scientific American, vol. 226 (June 1972): 91-101.

[3] L.E. Arend, J.N. Buehler, and G.R. Lockhead, "Difference Information In Brightness Perception," Perception & Psychophysics, vol. 9 (1971): 367-370.

[4] E.H Land, "The Retinex Theory Of Color Vision," Scientific American, vol. 237 (1977): 108-121.

perceived colors in adjacent regions are determined by the ratio of the reflectances at the edges between the regions. The luminances within uniform colored regions are "discounted" and the relative contrast at the edge determines the percept of color. Grossberg[5] incorporates this dominance of edge computations in a neural model of brightness perception that possesses two parallel edge-sensitive processes. Specifically, boundaries in the visual scene are synthesized by a boundary contour system and the brightnesses in the regions delineated by these boundaries are "filled-in" by a feature contour system.

Retinal and neural mechanisms enable the potential for the strong dependency of luminance judgments on both adjacent luminances and the presence, size, shape, and location of structures characterized by edges. What follows is further evidence for such context effects.

A. ADJACENT BORDER AND LINE EFFECTS

Basic luminance studies indicate that the luminance in an adjacent region can influence brightness perception. Liebowitz[6] presented a reference luminance patch to the left eye and a test patch to the right eye, and studied the perceived brightness between the two as the luminance of an "inducing" luminance patch presented to the left eye was varied. Increasing the luminance of an inducing patch

---

5 M.A. Cohen and S. Grossberg, "Neural Dynamics Of Brightness Perception: Features, Boundaries, Diffusion, and Resonance," Perception & Psychophysics, vol. 36, no. 5 (1985): 428-456.

6 H. Leibowitz, F.A. Mote, and W.R. Thurlow, "Simultaneous Contrast As a Function Of Separation Between Test and Inducing Fields," Journal of Experimental Psychology, vol. 46, no. 6 (1953): 453-456.

required additional test field luminance to obtain a brightness match with a reference patch. Moreover, when the separation between this third inducing patch and the test patch was increased, the inhibitory effect of the test patch on the brightness constancy between the reference and test patch was diminished. Consequently, absolute luminance and separation are both factors in contextual decisions.

Evidence that simple surrounding structures might influence brightness perception comes from experiments in which contrast detection thresholds were studied as a function of various manipulations of an adjacent border or edge. Early investigators studied the effects on contrast detection of the presence or completeness of a surrounding contour. Craik and Zangwill[7] found higher thresholds for a 10 minute test patch when the rectangle was positioned inside a larger "irregular" closed figure than when positioned outside the figure. Similarly, Youniss and Calvin[8] showed that the time required to correctly identify nonsense syllables was significantly greater when the targets were located within an enclosing contour or parallel lines. Horeman[9] subsequently confirmed this effect for ring-shaped fields that entirely enclosed the stimulus.

---

[7] K.J.W. Craik, and O.L. Zangwill, "Observations Relating To the Threshold Of a Small Figure Within the Contour Of a Closed-Line Figure," British Journal of Psychology, vol. 30 (1939): 139-150.

[8] J. Youniss and A.D. Calvin, "The Enclosing Contour Effect," Perceptual Motor Skills, vol. 13 (1961): 75-81.

[9] H.W. Horeman, "Inductive Brightness Depression As Influenced By Configurational Conditions," Vision Research, vol.3 (1963): 121-130.

Thresholds have also been shown to be influenced by the diameter of the enclosing contour. Fry and Bartley[10] varied the diameter of a 0.5 degree thick black ring surrounding a 0.75 degree stimulus spot. They noted a decrease in threshold with increasing area within the interior border of the surrounding ring. Furthermore, this decreasing effect extended to the 4 degree ring diameter within the 8 degree display. Wildman[11] also noted the threshold for a spot of light was higher at the edge of an illuminated field than either in the central illuminated region or the surrounding dark field.

Van der Wildt and Waarts[12] utilized sinusoidal gratings to measure contrast sensitivity in the presence of dark lines. They positioned two vertical dark lines parallel to the bars in the grating and manipulated the distance of the bars to the grating. They observed increased contrast sensitivity as the distance of the bars was increased, and the effect of the bars on contrast sensitivity persisted for separations of several degrees. In a set of similar experiments, Bijl, Koenderink, and Toet[13] measured contrast detection thresholds for circularly symmetric "blobs" described by a Gaussian luminance profile on a uniform background. They observed decreased thresholds for

---

10 G.A. Fry, and H. Bartley, "The Effect Of One Border In the Visual Field Upon the Threshold Of Another," American Journal of Physiology, vol. 112 (1935): 414-421.

11 K.N. Wildman, "Visual Sensitivity At an Edge," Vision Research, vol 14 (1974): 749-755.

12 G.J. van der Wildt, and R.G. Waarts, "Contrast Detection and Its Dependence On the Presence Of Edges and Lines In the Stimulus Field," Vision Research, vol. 23, no. 8 (1983): 821-830.

13 P. Bijl, J.J. Koenderink, A. Toet, "Visibility Of Blobs Wth a Gaussian Luminance Profile," Vision Research, vol. 29, no. 4 (1989): 447-456.

stimuli presented in the presence of an adjacent edge created by a luminance transition to a dark surround.

Even illusory contours are capable of affecting contrast detection thresholds. Coren and Theodor[14] measured increment thresholds for a spot of light located on either side of the locus of an illusory contour. They observed a threshold elevation in the central region of the figure as compared with a similar figure without the contour illusion. However, others have shown that the line-end contrast that contributes to the Ehrenstein illusion significantly lowers increment thresholds in the central region of such a figure.[15]

B. COMPLEX BACKGROUND

The more global effects of context on object detection that approach the complexity of context encountered in a medical image have been studied by inserting a target in a background containing objects of variable size, shape, luminance or density. Eriksen[16] studied multiple dimensions of heterogeneity among both a target object and the elements of the background. When the background objects were heterogeneous for hue, form, size, and brightness, location of target objects was slower than when background objects differed along a single dimension. And in heterogeneous background fields, target objects possessing unique values along several property dimensions

---

14 S. Coren and L.H. Theodor, "Neural Interactions and Subjective Contours," Perception, vol. 6 (1977): 107-111.

15 R.H. Day and M.K. Jory, "Visual Psychophysics and Physiology," J.C.Armington, J. Krauskopf, and B.R. Wooten, Symposium In Honor of Lorrin Riggs On Visual Psychophysics and Physiology, (New York: Academic Press, 1978).

16 C.W. Eriksen, "Object Location In a Complex Perceptual Field," Journal of Experimental Psychology, vol. 45 (1953): 126-132.

were located more rapidly than target objects defined by only a single unique property. Boynton and Bush[17] studied the recognition of geometrical target objects as a function of the number of objects in the background and stimulus viewing time. Logically, these initial studies revealed decreased recognition of the target form among increased number of forms when exposure time was decreased. When a target disc located in an array of background discs is distinguished from the background elements by luminance, increasing background density has an inhibitory effect on the conspicuity of the target. However, when the distinction between target and background is based on size, background density has no effect.[18,19]

C. OBJECT SUPERIORITY

There exists evidence that targets that are perceived as part of an object are detected more accurately than targets positioned among a random array of elements. When oriented line segments were presented briefly within a coherent three-dimensional drawing, they were identified more accurately than when the lines were presented in less unitary patterns.[20] Similarly, observers can detect vertical and horizontal target elements embedded within an array of "noise elements" when the target lines are displayed so they formed a "face-

---

[17] R.M. Boynton and W.R. Bush, "Recognition Of Forms Against a Complex Background," Journal of the Optical Society of America, vol. 46, no. 9 (1956): 758-764.

[18] S.E. Jenkins and B.L. Cole, "The Effect Of the Density Of Background Elements On the Conspicuity Of Objects," Vision Research, 22 (1982): 1241-1252.

[19] B.L. Cole and S.E. Jenkins, "The Effect Of Variability Of Background Elements On the Conspicuity Of Objects," Vision Research, vol. 24, no. 3 (1984): 261-270.

[20] N. Weisstein, and C.S. Harris, "Visual Detection Of Line Segments: An Object-Superiority Effect," Science, vol. 186 (Nov. 1977): 752-755.

like" pattern significantly better than when the target elements are displayed in random configurations.[21]

D. MEDICAL CONTEXT STUDIES

Medical researchers, recognizing that the visibility of lesions or other structures in a medical image depends on properties of structures surrounding the targeted object as well as properties of the object itself, have provided descriptions of lesion detectability and examples of contextual influences. One observation from chest film studies is that, in general, accuracy is higher for lesions in the upper quadrants than lower quadrants of the film, owing to the "obscuring" effect of the heart and large vascular patterns in the lower quadrant.[22] Secondly, anecdotal observations have fostered physiological and experimental proof that extraneous light impairs lesion detectability. The physiological mechanisms involved in light adaptation have been defined, and shown to decrease sensitivity to low contrast lesions in real images.[23]

Kundel and Revesz[24] have defined lesion conspicuity as lesion contrast divided by surround complexity. Lesion contrast is computed from the density change across the lesion border, and the rate of fluctuation of the surrounding region is used as an estimate of

---

[21] A. Gorea and B. Julesz, "Context Superiority In a Detection Task With Line-element Stimuli: A Low-level Effect," Perception, vol. 19 (1990): 5-16.

[22] C.A. Kelsey, R.D. Moseley, B.G. Brogdon, D.G. Bhave, and J. Hallberg, "Effect Of Size and Position On Chest Lesion Detection," American Journal of Roentgenology, vol. 129 (Aug. 1977): 205-208.

[23] B. Baxter, H. Ravindra, and R.A. Normann, "Changes In Lesion Detectability Caused By Light Adaptation In Retinal Photoreceptors," Investigative Radiology, vol.17, no. 4 (July-August 1982): 394-401.

[24] H.L. Kundel and G. Revesz, "Lesion Conspicuity, Structured Noise, and Film Reader Error," American Journal of Roentgenology, vol.126 (1976): 1233-1238.

complexity. The formula makes predictions about the conspicuity of lesions following contrast enhancement methods which may increase surround complexity as well as lesion contrast, and digital subtraction, which aims to increase the conspicuity fraction by reducing structural complexity.

Brogdon, *et.al.*,[25] produced two series of identical radiographs, except that a single inserted nodular lesion was shifted relative to adjacent structures in each pair of images. When the shifted pairs were viewed side-by-side, the shift of the lesion relative to its surround enabled significant improvement in observer performance.

Some of the most interesting demonstrations of contextual effects in medical images arise when several structures in an image contribute to the formation of subjective contours and illusory luminance distributions. A radiograph contains the superposition of shadows from all of the anatomical structures through which the x-ray beam passes. Combinations of adjacent shadows can be connected and perceived by the mind's eye as contours. In skeletal images, for instance, the shadows of osteophytes cast over the "lateral margin of vertebral bodies" can give the appearance of defects in the vertebral bodies.[26] Mach bands also appear in radiographs at the sharp-contrast

---

[25] B.G. Brogdon, R.D. Moseley, C.A. Kelsey, and J.R. Hallberg, "Perception Of Simulated Lung Lesions," Investigative Radiology, vol.13, no. 1 (Jan.-Feb. 1978): 12-15.

[26] R.H. Daffner, J.A. Gehweiler, and B.A. Rodan, "Subjective Contours and Illusory Roentgenographic Images," Applied Radiology, (July-Aug. 1984): 95-98.

borders between structures. A thin translucent line across the base of the dens may be misinterpreted as a cervical spine fracture.[27,28]

Clearly the effects of context on contrast detection tasks are important. This psychophysical evidence from the literature substantiates an emphasis for the inclusion of an understanding of contextual mechanisms in the modelling of human vision.

---

27 R.H. Daffner, "Pseudofracture Of the Dens: Mach Bands," American Journal of Roentgenology, vol. 128 (April 1977): 607-612.

28 E.J. Lane, A.V. Proto, and T.W. Philips, "Mach Bands and Density Perception," Radiology, vol. 121 (Oct. 1976): 9-17.

VII. TESTING CONTEXT EFFECTS

A. PREVIOUS ATTEMPTS

To correctly study the effects of surrounding context on local detection and discrimination tasks, stimuli must be presented in a homogeneous field that encompasses the entire field of vision. In this way, extraneous contextual cues from the experiment environment or standard display apparatus can be eliminated and the imposition of contextual manipulation controlled. Such a structureless field is called a ganzfeld, and its use in context studies is often conspicuously absent or insufficient for the application of results to medical imaging. Miller and Hall[1] studied the accuracy of perceptual judgements in a ganzfeld constructed with a uniformly-illuminated white background that was viewed with a clear plexiglass cylindrical annulus containing a "liquid fogging solution." Katz,[2,3] in studying aerospace applications, constructed a 270 degree curved white fiberglass projection screen and presented circular spots of light as targets with a slide projector. More recently, Bijl, et.al.[4] in their experiments with contrast detection, have presented stimuli on a CRT that is viewed through a uniformly-

---

[1] J.W. Miller and R.J. Hall, "Accuracy Of Orientation and Positioning In Homogeneous Visual Fields," Aerospace Medicine, vol 34 (April 1963): 337-341.

[2] M.S. Katz, W. Metlay, and P.A. Cirincione, "Effects Of Stimulus and Field Size On the Accuracy Of Orientation In the Homogeneous Environment," Perceptual and Motor Skills, vol. 20 (1965): 167-172.

[3] M.S. Katz, "Feedback and Accuracy Of Target Positioning In a Homogeneous Visual Field," American Journal of Psychology, vol. 80 (1967): 405-410.

[4] P. Bijl, J.J. Koenderink, A. Toet, "Visibility Of Blobs With a Gaussian Luminance Profile," Vision Research, vol. 29, no. 4 (1989): 447-456.

illuminated screen with a central aperture. Since the screen is placed very close to the viewer and the luminance and hue of the screen are made to match that of the CRT, the border of the aperture is out of focus and the combination of the screen and the CRT appears uniform and edgeless.

However, the few ganzfelds that have been proposed possess inherent limitations that make them insufficient for context experiments conducted with the intention of application in various fields of medical imaging: they are typically viewed monocularly or do not allow electronic presentation of greyscale images. The ganzfeld presented in this thesis was constructed in our visual perception laboratory in the UNC Department of Radiology in an attempt to surmount these traditional limitations in the study of visual context effects. It was designed by Eugene Johnston and Diane Rogers, and constructed by Timothy Cullip and the author. The design and preliminary results were presented at the 1991 ARVO Annual Meeting.[5]

B. PRESENT GANZFELD DESIGN

1. Physical Dimensions. The ganzfeld presented here consists of a projection screen stretched across a frame that subtends 104 degrees of visual angle in the vertical dimension and 131 degrees in the horizontal dimension at the 66 cm viewing distance. The central 65 degrees of the screen in the horizontal dimension are essentially flat,

---

[5] D.T. Puff, V. Klymenko, R.E. Johnston, C.A. Burbeck, and S.M. Pizer, "Long-Distance Context-Effects On Contrast Detection In a Ganzfeld," 1991 Meeting of the Association for Research in Vision and Opthalmology.

and the outer portions of the screen curve slowly inward toward the observer. The screen is illuminated by a high brightness slide projector positioned behind the seated observer. Images are presented on the center of the screen with a video projection monitor positioned behind the screen (Figures 7.1, 7.2, 7.3).

2. Luminance Cancellation. Targets projected with the monitor are presented on a uniform circular background that is blurred at the edge with a cosine function. The forward projection contains a mask with identical shape characteristics as the rear-projected background, designed so that when the two are aligned properly, the boundary between the two projections is virtually invisible (Figure 7.4). These two coincident projections create a maximum central, circular display diameter of 14 degrees.

3. Equipment Specifications. The backprojection is accomplished with a monochrome, 30 Hz interlaced Tektronix 634 monitor equipped with a custom-built high-brightness CRT. This monitor is fitted with a lens system to project, focus, and magnify the image. A Parallax Viper™,[6] videographics processor with a 2048 pixel buffer and 256 levels of greyscale, mounted on a Sun4 computer, drives the display. An Atlantic Model EKX-30SW slide projection system, containing a Kodak Carousel slide projector illuminated with a high efficiency (GE EXW) 500W Xenon bulb and a wide-angle 38mm lens illuminates the screen. Colored filters placed in front of both the front

[6] Parallax Graphics Inc., Santa Clara, CA.

and rear projection systems assist in the subjective match of the hue of the two systems.

4. Screen Characteristics. The ganzfeld screen is made from Edmund Scientific backprojection screen material. The material is translucent, allowing light from the backprojected image to pass through it with minimal scatter, and yet reflective enough to enable a uniform illumination from the forward projection.

The spatial frequency characteristics of projection screens are typically evaluated by measuring the contrast sensitivities for sine or square-wave gratings presented over a range of frequencies. Furthermore, contrast sensitivity measurements are made for a standard monitor as well as the projection screen, and the results are reported as a ratio of the two.[7] There were several limitations of this ganzfeld design that made such a thorough analysis impossible. First, measurements for a standard monitor would have had to have been made on a monitor other than the one used with the ganzfeld: the monitor used with the ganzfeld was equipped to project an image and could not be viewed directly. Second, the contrast of the monitor was set such that at even a single driving level above background the contrast of the gratings was sufficient to detect their presence. Therefore, the high-frequency cutoff, that grating frequency at which the gratings could not be resolved with 100 percent contrast, is reported here. At the 66 cm viewing distance used in the experiments, the high

---

[7] C.A. Burbeck and Y.L. Yap, "Spatial Filter Selection In Large-scale Spatial-interval Discrimination," Vision Research, vol. 30, no. 2 (1990): 262-272.

frequency cut-off of the screen for a square-wave grating with a mean luminance of 0.12 fL was 3.8 cycles/degree.

5. Luminance Characteristics. The luminances available for presentation on the screen, measured from the rear-projection video monitor after transmission through the screen, are plotted in Figure 7.5. Transmittance of rear-projected light through the screen was 3.2%. While the rear projection monitor was capable of output luminances of up to 600 fL, the shape of this luminance curve was largely dictated by the contrast and brightness required to form an adequate subjective match of the background image with the circle projected by the mask from the slide projector. Transmission of light from the forward projector to the screen over 371 cm was 0.4%, and reflectance of that light from the screen was 0.8%. A diagram of the luminance profile of the ganzfeld screen is provided in Figure 7.6. Luminance across the screen varied smoothly and was essentially uniform in the central region of the screen. The profile is not entirely uniform since the ganzfeld screen is rotated forward 25 degrees from vertical and the projector is elevated to cast light over the head of the observer. This places the top of the screen closer to the projector than the bottom.

VIII. EXPERIMENTAL DESIGN AND METHODS

An experiment was designed for implementation on the ganzfeld to test the effects of surround context on discrimination of a central target.

A. MOTIVATION.

The development of contrast enhancement assessment methods which incorporate a model of human perception have exerted a need for experiments which will characterize the contextual effects of surrounding conditions. To study the distance over which a boundary might exert a contextual influence on the perception at some position, an experiment was conducted that measured the contrast discrimination for a target as several surround conditions were presented. The surround conditions were rings of different diameters. In addition, contrast discrimination was measured for enclosing contours of different shapes and contrasts.

B. DESIGN

Contrast thresholds were measured for detecting the orientation of a C-shaped target (a 1 degree diameter circular disk with a $\pi/2$ wedge removed). This target allowed a 4AFC discrimination paradigm, as subjects were instructed to indicate the orientation (up, right, down, or left) of the removed wedge. Thresholds were measured using a transformed up-down method,[1] or "staircase," that has been advocated

---

[1] H. Levitt, "Adaptive Testing In Audiology," Scandanavian Audiology Supplement, vol. 6 (1978): 241-291.

for rapid threshold estimation in medical imaging visual tasks.[2] A transition rule was chosen so that the target intensity level was decreased by a fixed step only after two consecutive correct responses and increased by that step after a single incorrect response. This rule yields an estimate of the 70.7% threshold. The selected intensity stepsize is reported in each of the experiments. Data points reported for each experimental condition were computed by averaging the midpoints obtained from the descending transitions in the staircase, and are reported as threshold contrast, where contrast was calculated as $(C_{target} - C_{background}) / C_{background}$. In all cases, following a number of practice sets and a locate sequence, the staircase was executed for 14 turning points. Presentations of each of the conditions were interleaved. Subjects responded by entering a key on a keypad corresponding to the orientation of the indentation in the disk.

C. INITIAL STUDIES

An initial experiment was conducted in the summer of 1990 using the described target and several high-contrast annular surround conditions. These surrounding "rings" of width 1/4 degree were centered around the target. The target could be either lighter or darker than the background (targets presented above background are referred to as positive contrast targets). In each experiment, five surround conditions were studied: four rings of diameter 4, 6, 8, and 10 degrees and a condition in which no surround was present.

---

[2] V. Klymenko, S.M. Pizer, and R.E. Johnston, "Visual Psychophysics and Medical Imaging: Nonparametric Adaptive Method For Rapid Threshold Estimation In Sensitivity Experiments," IEEE Transactions on Medical Imaging, vol. 4 (Dec. 1990): 353-365.

Several physical conditions in these initial experiments differed from conditions in experiments conducted subsequently. Images were displayed with a Comtal frame buffer video system; computations carried out by this display system required approximately four seconds between each trial. Also, the mean background luminance of the ganzfeld was 0.0161 fL, which is in the scotopic luminance range. The stepsize used in the staircase threshold estimation procedure was 3.75×10^{-4} fL, or a contrast of 0.023. Finally, subjects were given unlimited time to view the target stimulus on each trial (the target was present on the screen until the subject responded).

The means for the four initial experiments are shown in Table 8.1. In the experiment in which a positive contrast target and black rings (0.003 fL) were presented, there was no significant effect of the manipulation of ring diameter on the mean contrast discrimination thresholds for the target ($F(3)=15.63$, Greenhouse-Geisser Epsilon[1,2] (G-G) =0.1577). Furthermore, mean thresholds in the no-ring condition were not significantly different from the combined means for the surrounding ring conditions ($F(1)=24.84$, $p=0.1261$). The data for the two subjects for this experiment are shown Figure 8.1. These combined means for two subjects indicate, however, increasing discrimination thresholds with increasing ring diameter and further exhibit an

---

[1] The Greenhouse-Geisser Epilson is a measure of the probability of rejecting the null hypothesis of equal means that incorporates a correction for unequal variances between treatment conditions in a within-subjects design. When the number of observations allowed its calculation, this G-G statistic, a more conservative estimate of probability, was used in the analysis.

[2] S.E. Maxwell and H.D. Delaney, Desiging Experiments and Analyzing Data (Belmont, California: Wadsworth Publishing Company, 1990),475-479.

insignificant but notable increase for the condition in which no surround was presented. When the positive contrast target was presented with surrounding white (0.0849 fL) rings, the four ring diameters again failed to significantly influence the discrimination thresholds ($F(3)=1.52$, G-G=0.4337). Likewise, mean thresholds in the no-ring condition were not significantly different from the combined mean thresholds from the ring conditions ($F(1)=0.2495$, $p=0.2495$, see Figure 8.2).

In the experiments in which a negative contrast target and black rings were presented, no significant effect of ring diameter was observed ($F(3)=1.40$, G-G=0.4463). However, the mean contrast discrimination thresholds for the two subjects in the no-ring condition were significantly higher than the combined means from the black ring conditions ($F(1)=1270.73$, $p=0.0179$). These data are plotted in Figure 8.3. Finally, in the fourth experiment in which the negative contrast target was presented with surrounding white rings, no significant effect of ring diameter was obtained ($F(3)=0.2336$, G-G=0.3557), and the means in the no-ring condition were also not significantly different from the combined means from the ring conditions ($F(1)=10.95$, $p=0.1868$, see Figure 8.4).

D. PRESENT EXPERIMENTS

Following the installation of the Viper™ videographics display system and concerted attempts to increase the overall luminance of the system, a series of experiments was conducted. In all cases the physical conditions are those of its current status as reported in the ganzfeld design section. Intertrial computations required approximately one second. The target was present for 0.5 seconds and then removed. The stepsize used in the staircase procedure was 8.12×10^{-4} fL (7.2×10^{-3} contrast).

1. Surround Presence and Proximity.

Because the most promising effects of both ring presence and proximity were originally believed to exist in the experiments with a positive contrast target and black ring, that experiment was again conducted under the new system. This time, four surrounding conditions were studied: three rings of 3, 6, and 9 degrees and the no-ring condition. The data for the four subjects are plotted Figure 8.5, and means for this and several later experiments are presented in Table 8.2. Under these experimental conditions, there was no significant effect of ring proximity across the three diameters ($F(2)=0.76$, G-G=0.4490). There was also no significant elevation of thresholds in the no-ring condition relative to the combined black ring conditions ($F(1)=1.71$, $p=0.2827$).

The luminance and presentation characteristics of the original system were then approximated in an attempt to replicate the original findings. Subjects wore glasses fitted with neutral density filters to decrease the overall luminance of the present system to that of the original system. The luminance of these experiments, 0.011 fL, was made as close as possible to the luminance of the original experiments (0.0161 fL). The intertrial interval was intentionally slowed to approximate the timing of trials in the original experiment. Subjects were again given unlimited time to view the target and respond. Figure 8.6 reflects data for three subjects under these modified conditions. Thresholds were elevated overall, but there was no effect on the mean discrimination thresholds of changes in ring diameter (F(1)=0.11, G-G=0.7673). The difference between the combined means from the ring conditions and the means from the no-ring condition was also not significant (F(1)=13.85, p=0.0652). However, the statistical results from this analysis are nearly significant, and the means from Table 8.2 do indicate an elevation in the no-ring condition.

In spite of the insignificant findings, it was believed that the luminance and presentation characteristics of the original design were responsible for elevated discrimination thresholds in the conditions in which no ring was presented surrounding the target. At this point, a systematic study was undertaken to determine which factor or factors were responsible for inducing the noted elevated thresholds in the no-ring condition. To reiterate, the factors under consideration were 1) the overall luminance of the system, 2) the intertrial interval, and 3) the target presentation duration. Individual modifications in each experiment reflect alterations to the design or luminance of the present status of the ganzfeld system to approximate the original conditions. Again, a positive contrast target and black rings were used.

Figure 8.7 shows the results for three subjects of returning to the four-second intertrial interval. While the combined means for the ring conditions were not significantly different from the no-ring condition (F(1)=10.25, p=0.0853), the means in Table 8.2 do indicate an increase in the no-ring condition. Figure 8.8 shows the results of returning to the overall luminance of the original system. This manipulation clearly caused no elevation of mean thresholds in the no-ring condition (F(1)=0.40, p=0.5912). Figure 8.9 shows the results of allowing subjects unlimited time to view the target, while maintaining the higher luminance level and short intertrial duration of the present system. There appears to be no effect at the no-ring position in this case (F(1)=0.71, p=0.5545).

Figure 8.10 reflects data for two subjects for an experiment in which the original low background luminance was presented, the slow intertrial duration was imposed, and the target was presented for 500ms. For this condition, thresholds in the no-ring condition were significantly elevated (F(1)=272.05, p=0.0385). As will be developed in the discussion, it might be expected that this condition would indeed display the largest effect of the ganzfeld condition.

Results from an experiment with a positive contrast target and white rings conducted under the present ganzfeld system conditions are shown in Figure 8.11. Like the experiments with the black ring under the present system, there is no effect on contrast discrimination thresholds of ring proximity across the three ring diameters (F(2)=2.22, G-G=0.2156). Similarly, there is no significant difference between the means in the no-ring condition and the combined means for the three ring conditions (F(1)=6.23, p=0.0880). The original system conditions were approximated for this experiment as well, and the results are shown in Figure 8.12. There was no significant effect of ring diameter

(F(2)=1.53, G-G=0.3376). However, a significant increase in the means in the no-ring condition is noted (F(1)=66.10, p=0.0148).

2. Surround Shape.

The effect of surround shape on contrast discrimination was also studied. A six degree diameter ring and a square, diamond, and four dots with "widths" equivalent to the diameter of the ring, as well as a no-ring condition, were studied. In constructing these shapes, the length of the side of the square was made equal to the diameter of the ring, the diamond had the same dimensions as the square, and the four dots were positioned at the same locations as the vertices of the square. The results, shown in Figure 8.13, indicate that the shape of the surround has no effect on discrimination thresholds under these conditions (F(3)=1.59, G-G=0.4271).

3. Surround Contrast

The influence of the polarity of ring contrast was studied in an experiment containing both black and white surrounding rings. Previous experiments with either just black or just white ring surrounds were conducted separately; to accurately make comparisons between ring polarities these rings had to be studied together in a single experiment. The experiment consisted of seven conditions: the 3, 6, and 9 degree black and white rings, and the no-ring condition. The results are reported for three subjects in Figures 8.14, 8.15, and 8.16. The mean discrimination thresholds were not significantly different for the two ring polarities (F(1)=1.03, p=0.4165).

IX. DISCUSSION

A. CONTEXT EXPERIMENTS

At the time that the context studies under the original ganzfeld luminance and presentation conditions were performed, graphical analysis of the data suggested a small effect of increasing thresholds with increasing ring diameter for the experiments with positive contrast target and black surrounding rings. That experiment furthermore exhibited what was believed to be a significant elevation in thresholds in the structureless surround condition. It had been hypothesized that the different ring diameters might have a systematic effect on discrimination thresholds, and because that experiment yielded the most promising results in that regard, it was used as the basis for subsequent experiments.

Following the installation of a new videographics presentation system, several changes were made to the luminance and design of the experiment. In order to approach the luminance conditions characteristic of standard medical image viewing tasks, the overall background luminance the ganzfeld display was increased by a factor of ten to its present luminance of 0.112 fL. The new videographics processor was capable of performing display manipulations much more rapidly than the previous system, and a shorter intertrial interval could be used. Finally, in order to prevent extended scrutiny of the target and thereby emphasize any differences that might exist for discrimination in the different surround conditions, the target presentation duration was limited to 500 ms. When the experiment with a positive contrast target and black ring was attempted under these new conditions, there was no apparent effect of ring size and the no-ring condition was not elevated with respect to the ring conditions. Yet when the original luminance and presentation conditions were approximated for the same experiment, results similar to those collected in the initial context studies were obtained.

It was apparent from the results from the two experimental conditions that several design or physical characteristics of the initial studies contributed to an elevation of thresholds in the conditions with no surrounding ring. The ring diameter effect was consistently small, and attention to it as a manipulation was diverted in order to address the differences in the no-ring condition in the two experimental conditions. It was hypothesized that the low luminance conditions in the original studies may have caused accommodation errors: during the intertrial interval when no stimuli were present on the screen, subjects' accommodation may have drifted to a distance in front of or behind the plane of the screen. Furthermore, the long intertrial interval in the initial experiments would have provided the time for accommodative drift or other movements of fixation away from the central target presentation region. Since the ganzfeld theoretically provides no cues for reference, both accommodation and fixation drift in the intertrial interval were possible. In the no-ring condition, the target was presented without a surrounding ring that could have aided in proper return of accommodation and fixation. If subjects were given unlimited time to make a discrimination about the target, the effects of accommodation and fixation errors might be partially or entirely overcome by search and scrutiny.

From this it was hypothesized that the no-ring condition thresholds might be highest for the experimental conditions in which the luminance was low, the intertrial interval long, and the presentation duration short. The experiments conducted with the new system in which the intertrial interval was slowed or the luminance was reduced indicate that each of those variables alone were not able to induce an elevation of the thresholds in the no-ring condition. However, for the experiment in which all of these conditions were present, thresholds in the no-ring condition were indeed significantly higher.

In all of the experiments, the manipulation of ring diameter did not systematically effect the contrast discrimination thresholds. Furthermore, surround shape and surround contrast polarity were not observed to effect contrast discrimination thresholds in any systematic way.

These experiments show that under certain experimental conditions in a ganzfeld, thresholds for the discrimination of a target within the structureless field of the ganzfeld may be significantly elevated. More importantly, the presence of a surrounding edge at distances of up to 4 or 5 degrees may provide significant contextual information in that discrimination decision.

B. PRESENT GANZFELD DESIGN LIMITATIONS.

The maximum luminance of the present ganzfeld design is in the mesopic luminance range, where both the rods and cones in the retina are active. Cones, which are active primarily in luminance conditions above 1 fL, have far greater acuity than rods, which are responsible for viewing at lower luminances. Medical images are presented in very bright viewing conditions so that acuity is maximal for the intricate visual judgments involved in the viewing task. Application of the results from the present ganzfeld design to medical imaging must be done with a consideration of these lower luminance levels.

In order to accommodate both a forward and backprojection, the ganzfeld screen possessed a translucence that allowed some degree of reflectance but also caused a blurring of the rear-projected image. Target discrimination was therefore judged for a target of very low contrast and blurred edge characteristics. The blurred edges of the target and surrounding ring edges may have to some extent diminished contrast discrimination differences between the surround conditions.

Under higher luminance conditions, the luminance transition from the circular back-projected background to the surrounding forward projection was more apparent. While this transition was a low frequency transition that could not be categorized as an edge or structural influence, it may have been helpful in localizing the center of the screen in the condition where no ring was presented surrounding the target.

C. APPLICATION TO VISUAL MODELING

The results from these context experiment indicate that edges can exert a contextual influence on local discrimination decisions from a substantial distance. While the experiments showed that the characteristics of that edge, its relative proximity, shape, or contrast, were not significant factors, its mere presence can influence the perception of the target. Visual models which compute shape by calculating a grouping of local points in the construction of an object must determine the contribution of individual points relative to intensity variations across a large distance in the scene or image. Thus, methods of medical image contrast enhancement assessment which utilize a visual model to define fundamental visual tasks must incorporate this notion of contextual influence in determining an assessment of image quality.

Table 8.1. Mean Contrast Discrimination Thresholds For Five Surround Conditions Acquired In Initial Context Studies. The means represent contrast discrimination threshold measurements for two subjects for positive and negative contrast targets centered within surrounding rings of 4, 6, 8, or 10 degrees diameter, as well as within a no-ring condition. Standard deviations are shown in parentheses. Background luminance was 0.0161 fL.

Positive Contrast Target

	4 degrees	6 degrees	8 degrees	10 degrees	no ring
Black Ring	0.1883 (0.011)	0.2392 (0.009)	0.2567 (0.002)	0.2704 (0.019)	0.3136 (0.026)
White Ring	0.2288 (0.001)	0.2367 (0.033)	0.2512 (0.042)	0.2656 (0.012)	0.3450 (0.039)

Negative Contrast Target

	4 degrees	6 degrees	8 degrees	10 degrees	no ring
Black Ring	0.2130 (0.032)	0.2259 (0.040)	0.2375 (0.049)	0.2271 (0.021)	0.2890 (0.038)
White Ring	0.2738 (0.039)	0.2508 (0.054)	0.2732 (0.096)	0.3242 (0.089)	0.3126 (0.083)

Table 8.2. Mean Contrast Discrimination Thresholds For a Positive Contrast Target and Surrounding Black Ring. The means represent contrast discrimination thresholds measured for targets within surrounding rings of 3, 6, and 9 degrees (as well as no ring) under different luminance and timing conditions. Standard deviations are shown in parentheses. In the high overall luminance condition, the background luminance of the ganzfeld display was 0.112 fL, while the luminance for the low overall luminance condition was 0.011 fL. Targets were presented following either a fast (1 sec.) or slow (4 sec.) intertrial interval (ITI). Two target presentation conditions are shown: targets were presented for 500 ms or for an unlimited duration.

HIGH OVERALL LUMINANCE

Unlimited Target Presentation Duration

	3 degrees	6 degrees	9 degrees	no ring
Fast ITI	0.1067 (0.028)	0.1069 (0.023)	0.1106 (0.024)	0.1167 (0.040)

500 ms Target Presentation Duration

	3 degrees	6 degrees	9 degrees	no ring
Slow ITI	0.1476 (0.034)	0.1275 (0.046)	0.1408 (0.026)	0.1917 (0.062)
Fast ITI	0.1287 (0.038)	0.1328 (0.027)	0.1382 (0.034)	0.1439 (0.035)

LOW OVERALL LUMINANCE

Unlimited Target Presentation Duration

	3 degrees	6 degrees	9 degrees	no ring
Slow ITI	0.2647 (0.082)	0.2645 (0.083)	0.2591 (0.106)	0.3528 (0.100)

500 ms Target Presentation Duration

	3 degrees	6 degrees	9 degrees	no ring
Slow ITI	0.2590 (0.030)	0.2680 (0.053)	0.2605 (0.005)	0.3897 (0.018)
Fast ITI	0.5454 (0.028)	0.5820 (0.038)	0.4690 (0.127)	0.5570 (0.025)

Table 8.3. Mean Contrast Discrimination Thresholds For a Positive Contrast Target and Surrounding White Ring. Targets were centered within surrounding rings of 3, 6, and 9 degrees diameter, as well as within a no-ring condition. Standard deviations are shown in parentheses. Background luminance was 0.112 fL in the high luminance condition, and 0.011 fL in the low luminance condition. The indicated intertrial intervals (ITI's) between target presentations were 1 sec. (fast) or 4 sec. (slow). Two target presentation conditions are shown: targets were presented for 500 ms or for an unlimited duration.

High Luminance, Fast ITI, and 500 ms Target Presentation Duration

3 degrees	6 degrees	9 degrees	no ring
0.1036 (0.012)	0.1231 (0.017)	0.1189 (0.014)	0.1315 (0.021)

Low Luminance, Slow ITI, and Unlimited Target Presentation Duration

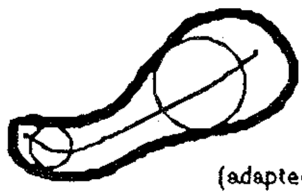
3 degrees	6 degrees	9 degrees	no ring
0.2117 (0.069)	0.2323 (0.044)	0.2695 (0.091)	0.3023 (0.051)

Table 8.4. Mean Contrast Discrimination Thresholds For a Positive Contrast Target and Several Surrounding Shapes. Standard devations are shown in parentheses. Targets were centered within surrounding shapes with an equivalent width to that of the 6 degree diameter ring. Background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec.

circle	square	diamond	four dots	no ring
0.1801 (0.120)	0.1861 (0.132)	0.1929 (0.153)	0.2088 (0.134)	0.1871 (0.112)

Table 8.5. Mean Contrast Discrimination Thresholds For a Positive Contrast Target Within White and Black Surrounding Ring Conditions. Standard devations are shown in parentheses. Targets were centered within surrounding rings of 3, 6, and 9 degrees diameter and well as within the no-ring condition. Background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec.

	Positive Contrast Target			
	3 degrees	6 degrees	9 degrees	no ring
Black Ring	0.1091 (0.038)	0.1067 (0.015)	0.1401 (0.046)	0.1382 (0.029)
White Ring	0.1106 (0.036)	0.1114 (0.034)	0.1313 (0.031)	0.1382 (0.029)



(adapted from Pizer, Coggins, and Burbeck, 1991)

Figure 5.1. The multiscale medial model represents an object's axis and edge via bilateral engagement of circular receptive fields.

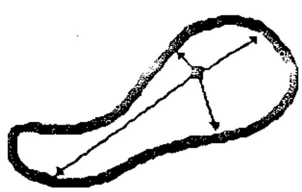


Figure 5.2. At every position in the visual scene the multiscale medial model applies a family of receptive fields possessing different scale responses. Thus edges from different locations in the object, as well as edges from adjacent structures, are considered at different levels of scale in the formation of the object.

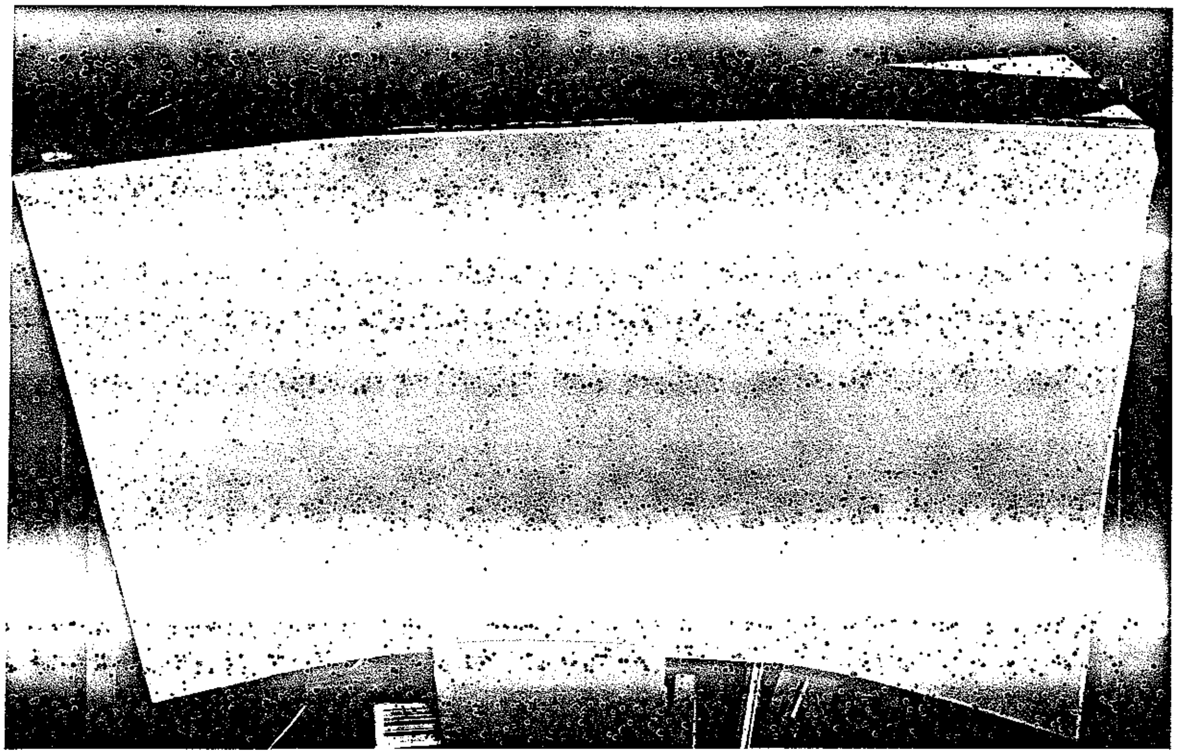


Figure 7.1. The ganzfeld presented in this thesis was housed in the UNC Department of Radiology Visual Perception Laboratory.

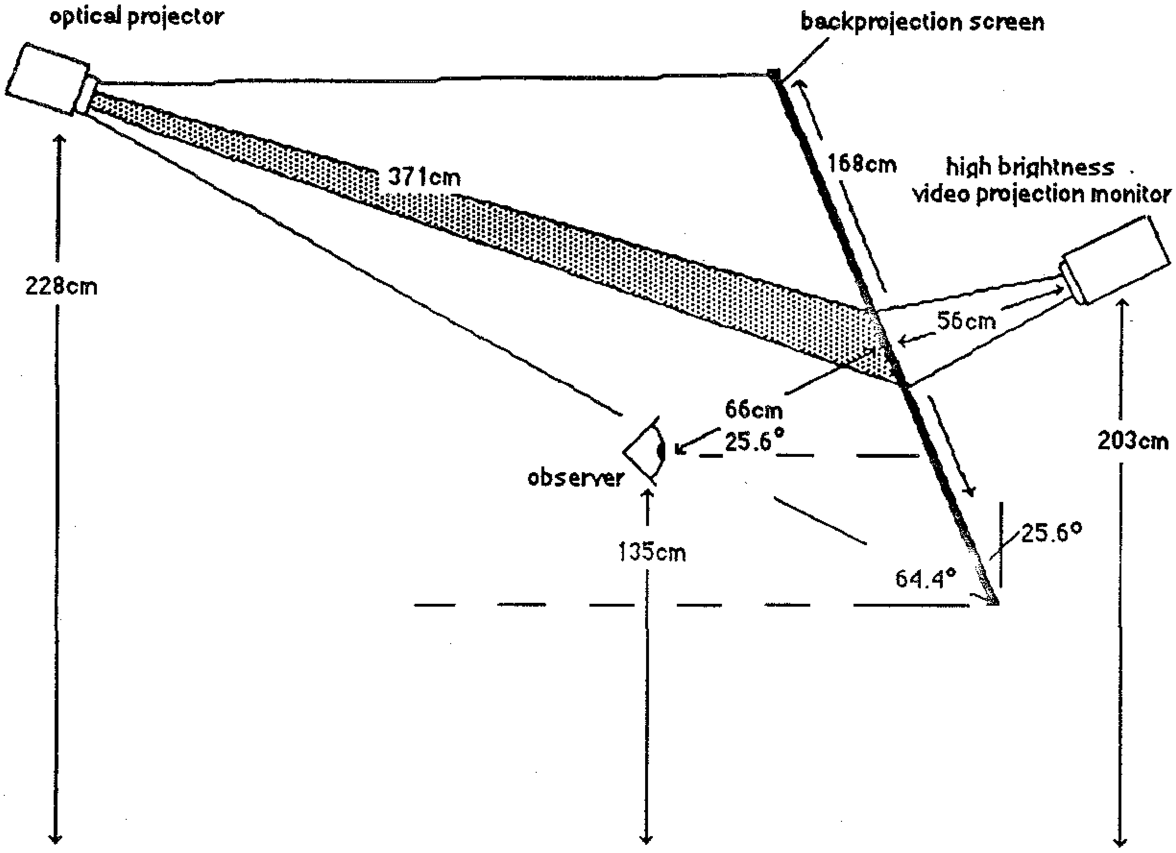


Figure 7.2. The physical dimensions of the ganzfeld and its component projection systems are shown in this side-view.

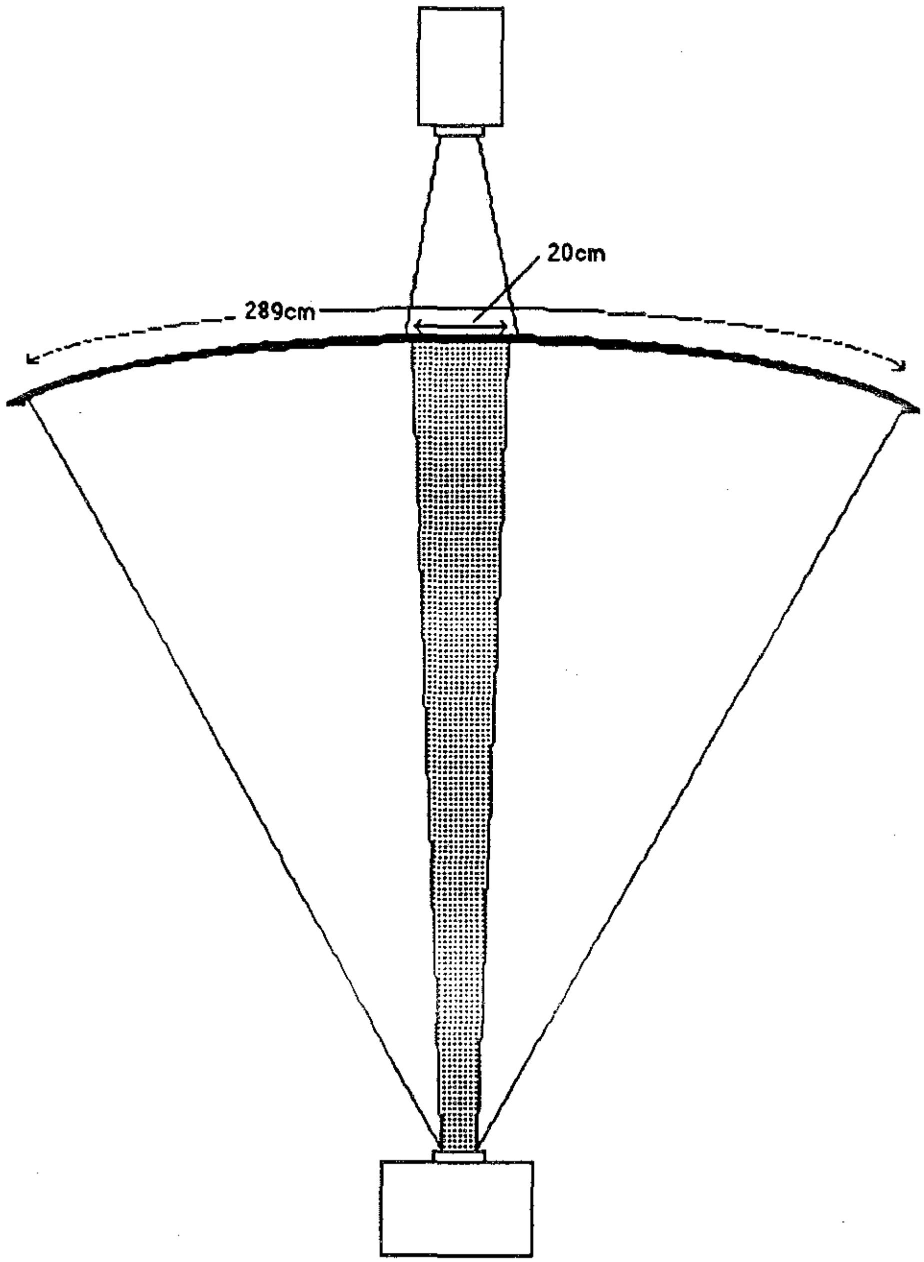


Figure 7.3. This figure depicts the ganzfeld and the projection systems as viewed from above.

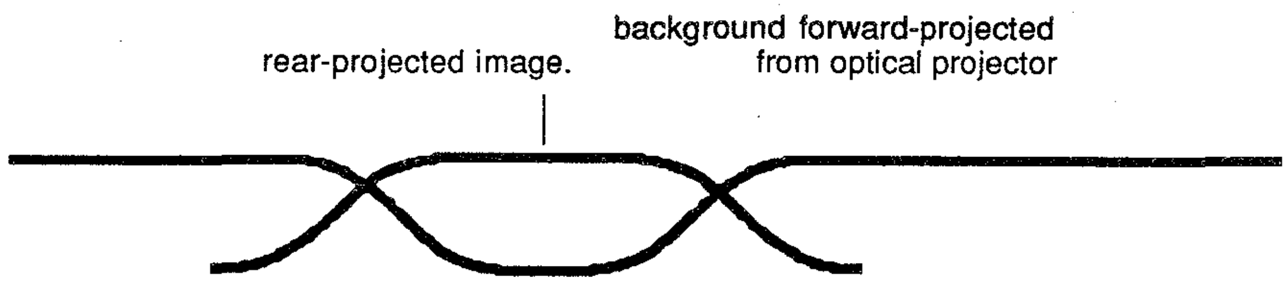


Figure 7.4. The luminance cancellation of the rear and forward projections are shown here. The luminance profiles both roll-off as a cosine function, and should, when projected together, provide a uniform background across the entire ganzfeld screen. The central region is then available for the presentation of greyscale images.

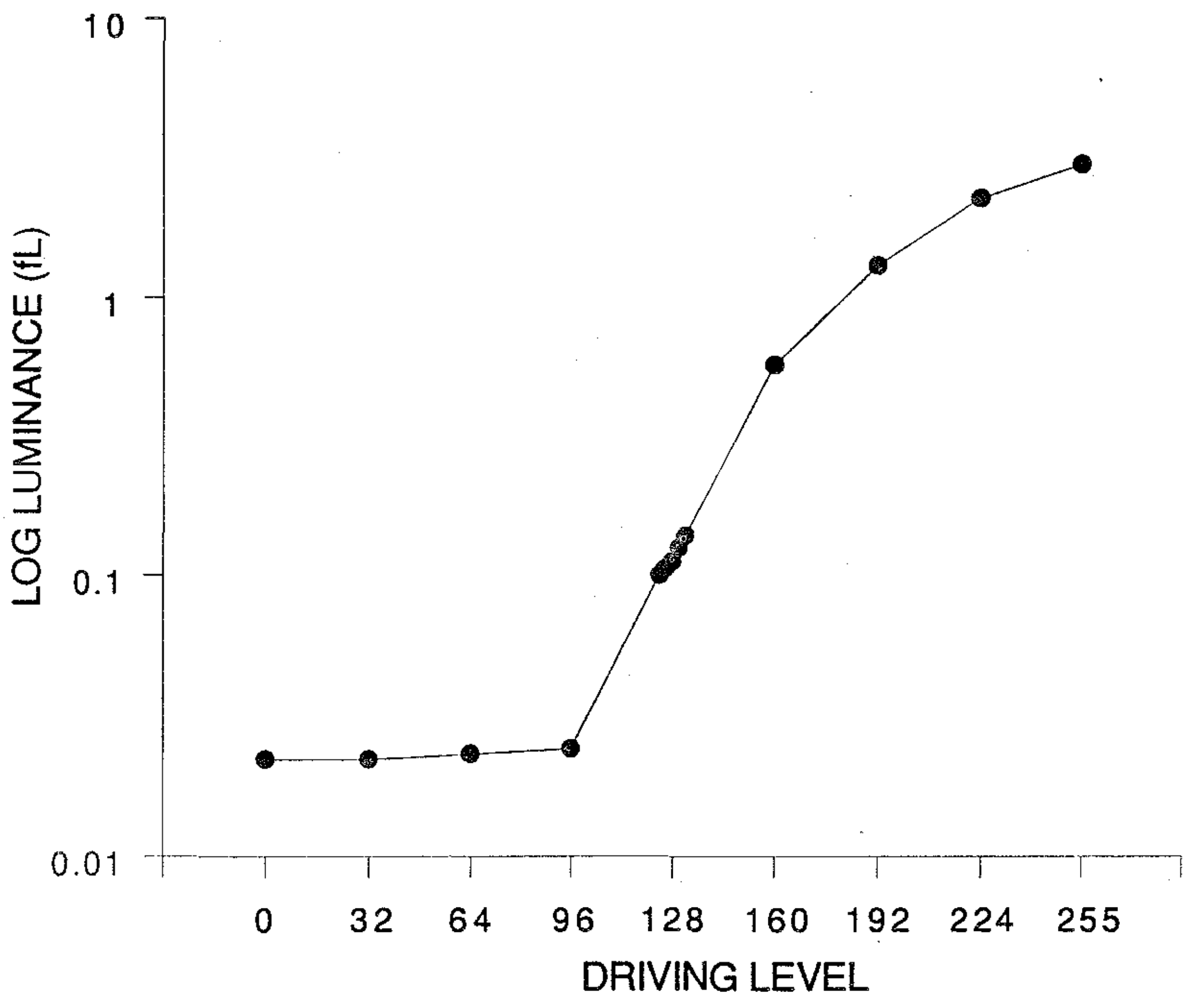


Figure 7.5. This plot shows the luminance curve of the rear-projected display intensities. This luminance curve was measured 2 in. from the ganzfeld screen in the central viewing area, and depicts the luminances available for target and background display in the experiments described.

0.199	0.249	0.214	0.182
0.134	0.122	0.106	0.0997
0.0884	0.0956	0.0772	0.0794

Figure 7.6. The luminance profile of the ganzfeld screen is shown here. The values are in units of fL. The measurements were made with the photometer oriented 30 deg. from horizontal at 2 inches from the screen.

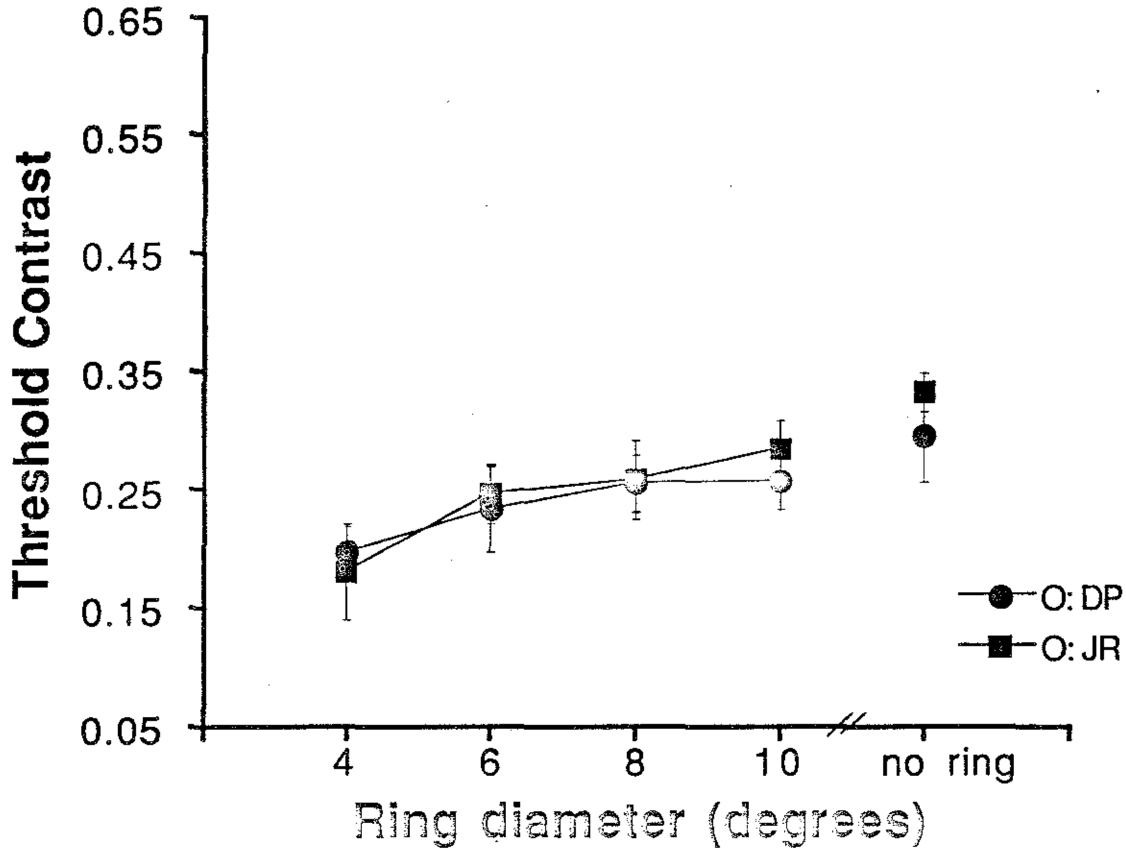


Figure 8.1. Contrast discrimination thresholds for a **positive contrast** target are plotted as a function of surrounding **black ring** diameter. This experiment was conducted under the original luminance and presentation conditions: the background luminance was 0.0161 fL, and targets were presented for an unlimited duration following an ITI of 4 seconds. Data for two subjects are plotted.

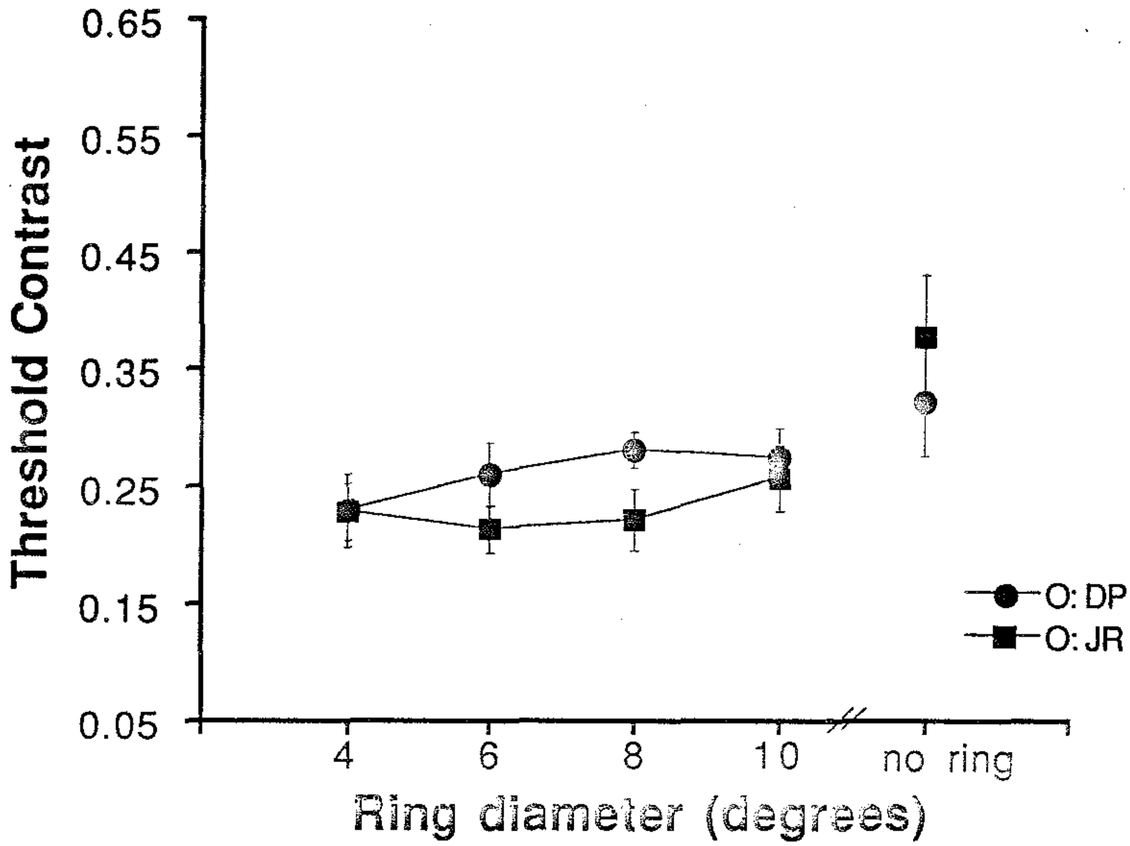


Figure 8.2. Contrast discrimination thresholds for a **positive contrast** target are plotted as a function of surrounding **white ring** diameter. The experiment was conducted under the original luminance and presentation conditions: the background luminance was 0.0161 fL, and targets were presented for an unlimited duration following an ITI of 4 seconds.

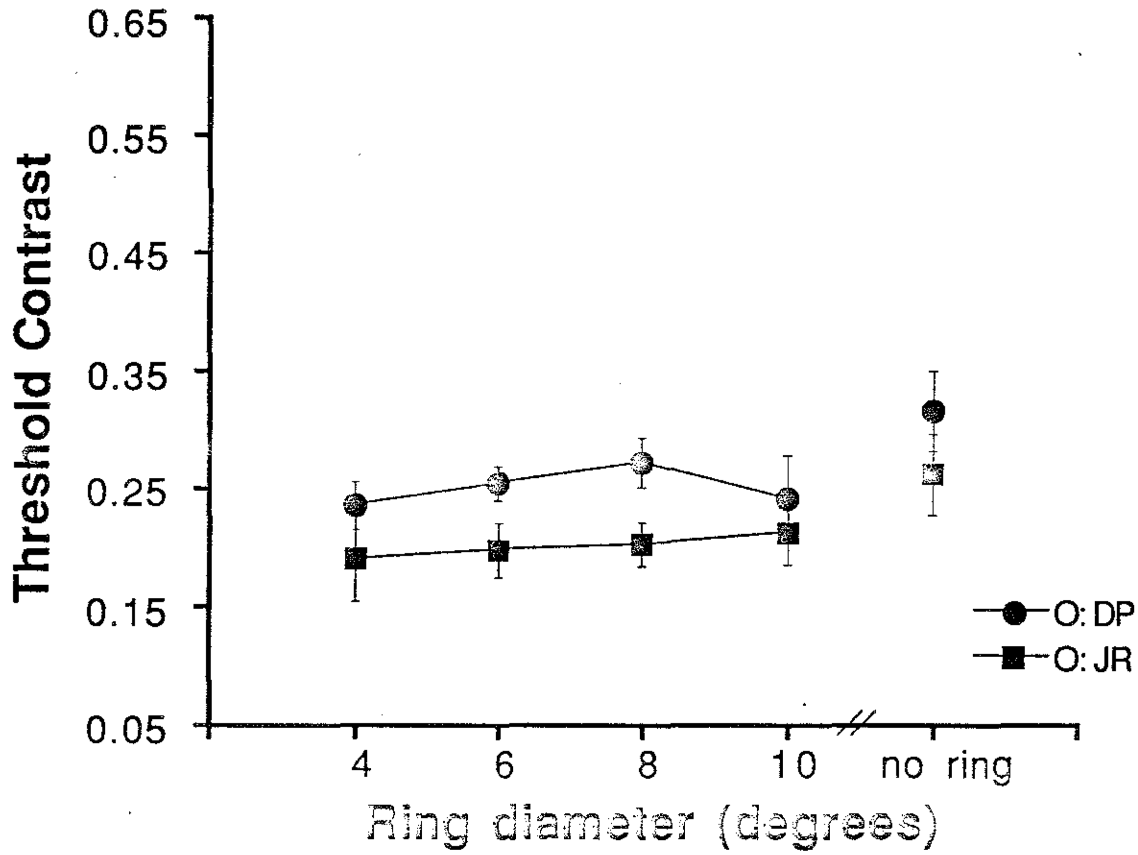


Figure 8.3. Contrast discrimination thresholds for a **negative contrast** target are plotted as a function of surrounding **black ring** diameter. The experiment was conducted under the original luminance and presentation conditions: the background luminance was 0.0161 fL, and targets were presented for an unlimited duration following an ITI of 4 seconds.

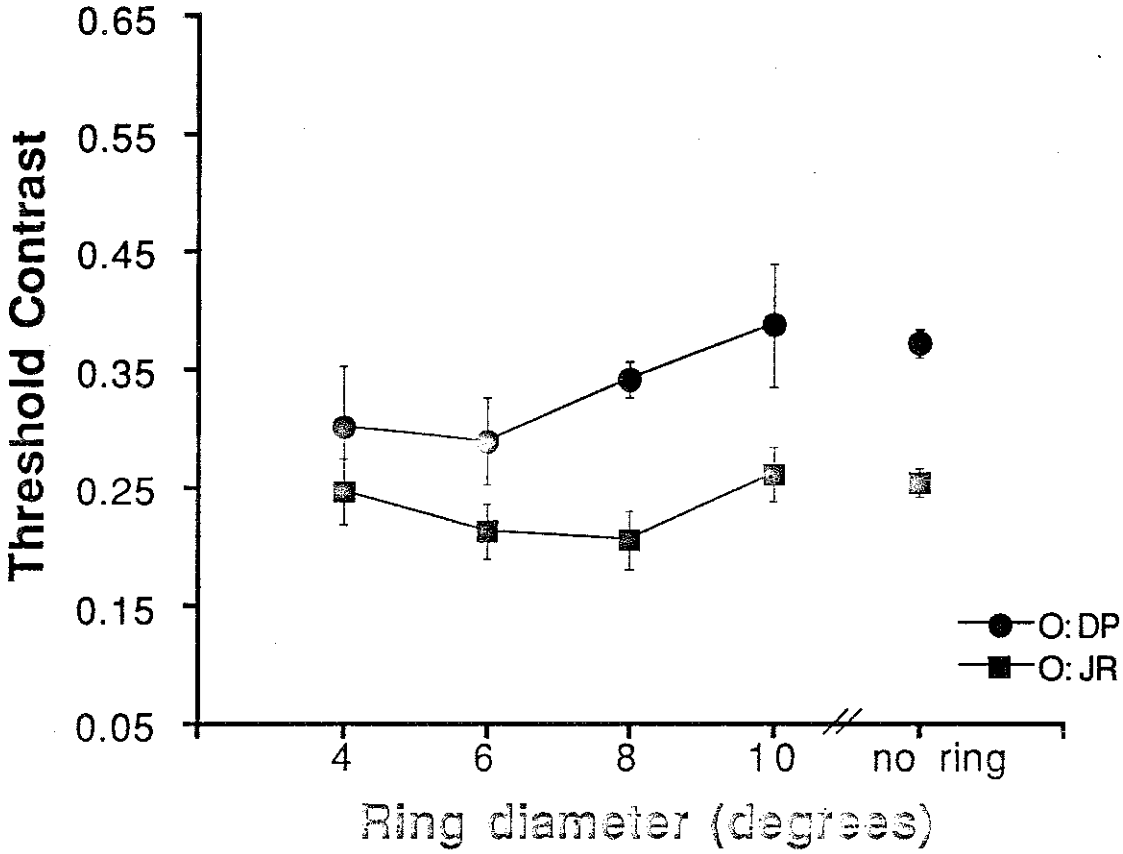


Figure 8.4. Contrast discrimination thresholds for a **negative contrast** target are plotted as a function of surrounding **white ring** diameter. The experiment was conducted under the original luminance and presentation conditions: the background luminance was 0.0161 fL, and targets were presented for an unlimited duration following an ITI of 4 seconds.

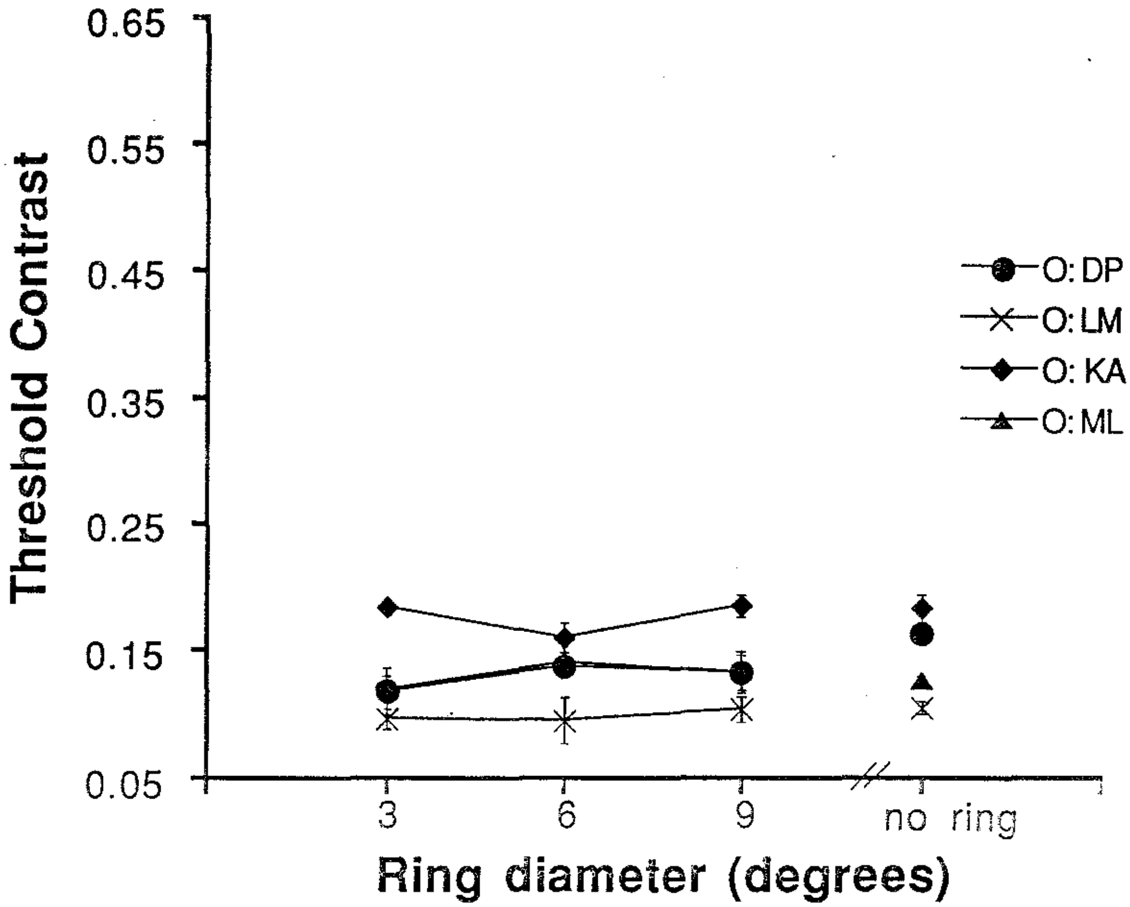


Figure 8.5. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding black ring diameter. The experiment was conducted under the present ganzfeld conditions: the background luminance was 0.112 fL, and targets were presented for 500 ms following an ITI of 4 seconds.

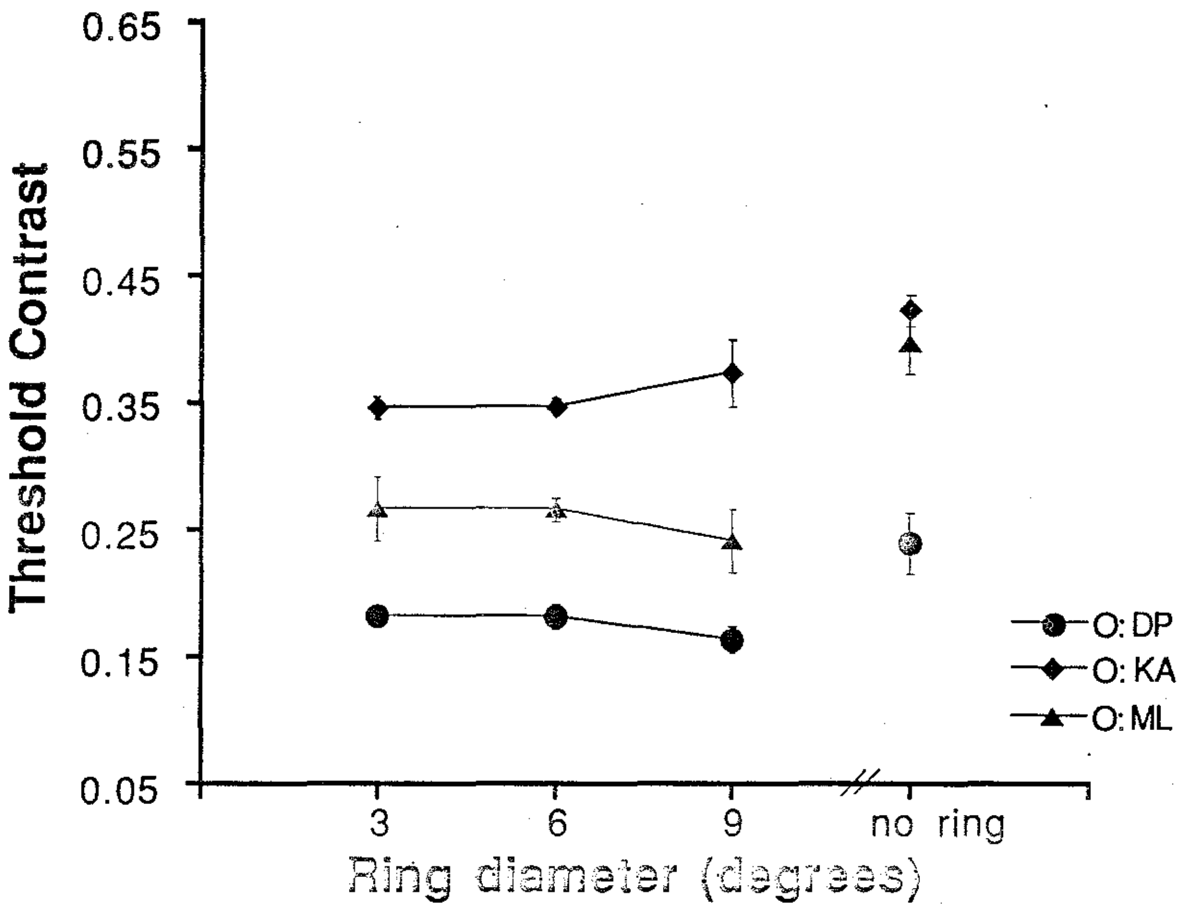


Figure 8.6. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding black ring diameter under **simulated original** luminance and presentation conditions. The background luminance was 0.011 fL. Targets were presented for an unlimited duration following an ITI of 4 sec.

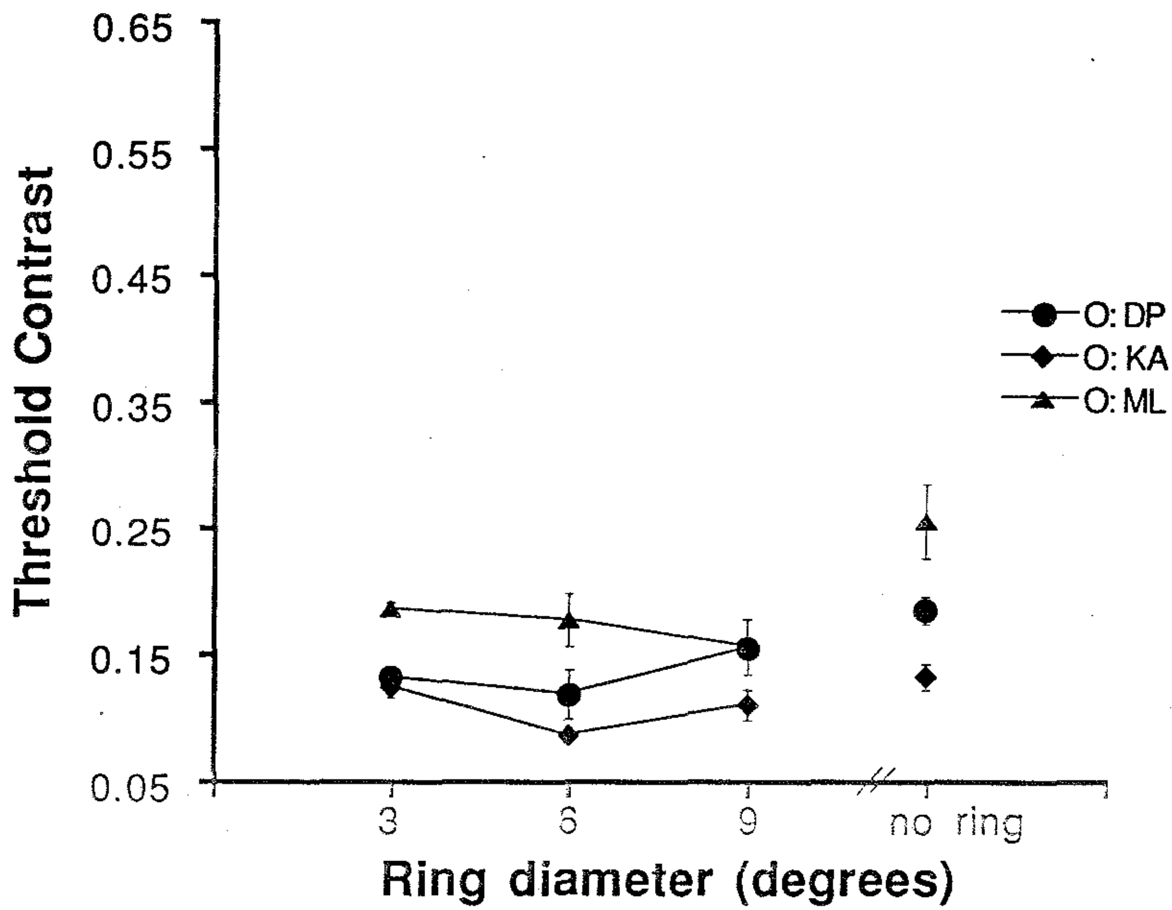


Figure 8.7. Contrast discrimination thresholds for a positive contrast target presented with a slow ITI are plotted as afunction of surrounding black ring diameter. The background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 4 sec.

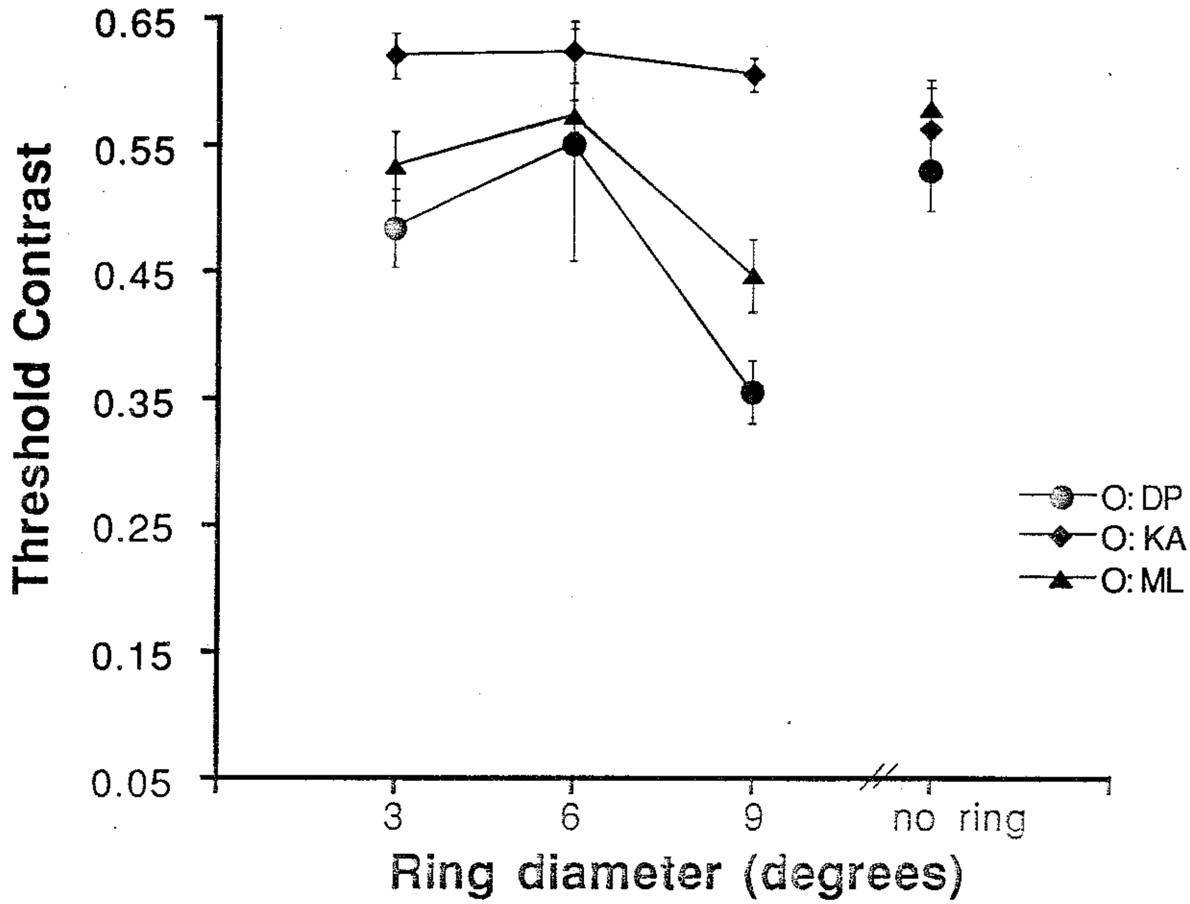


Figure 8.8. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding black ring diameter. The experiments were conducted under **low luminance** conditions: the background luminance was 0.011 fL. Targets were presented for 500 ms following an ITI of 1 sec.

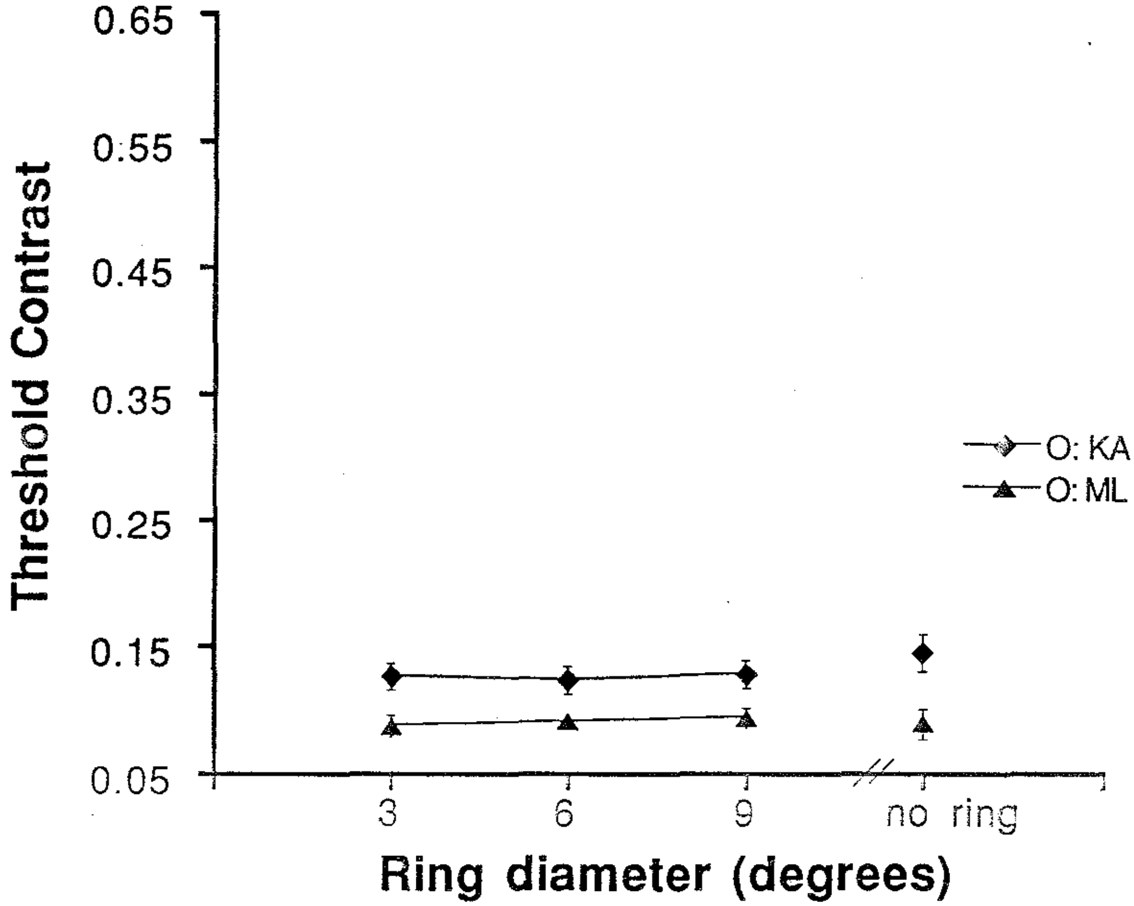


Figure 8.9. Contrast discrimination thresholds for a positive contrast target presented for an **unlimited duration** are plotted as a function of surrounding black ring diameter. Background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec.

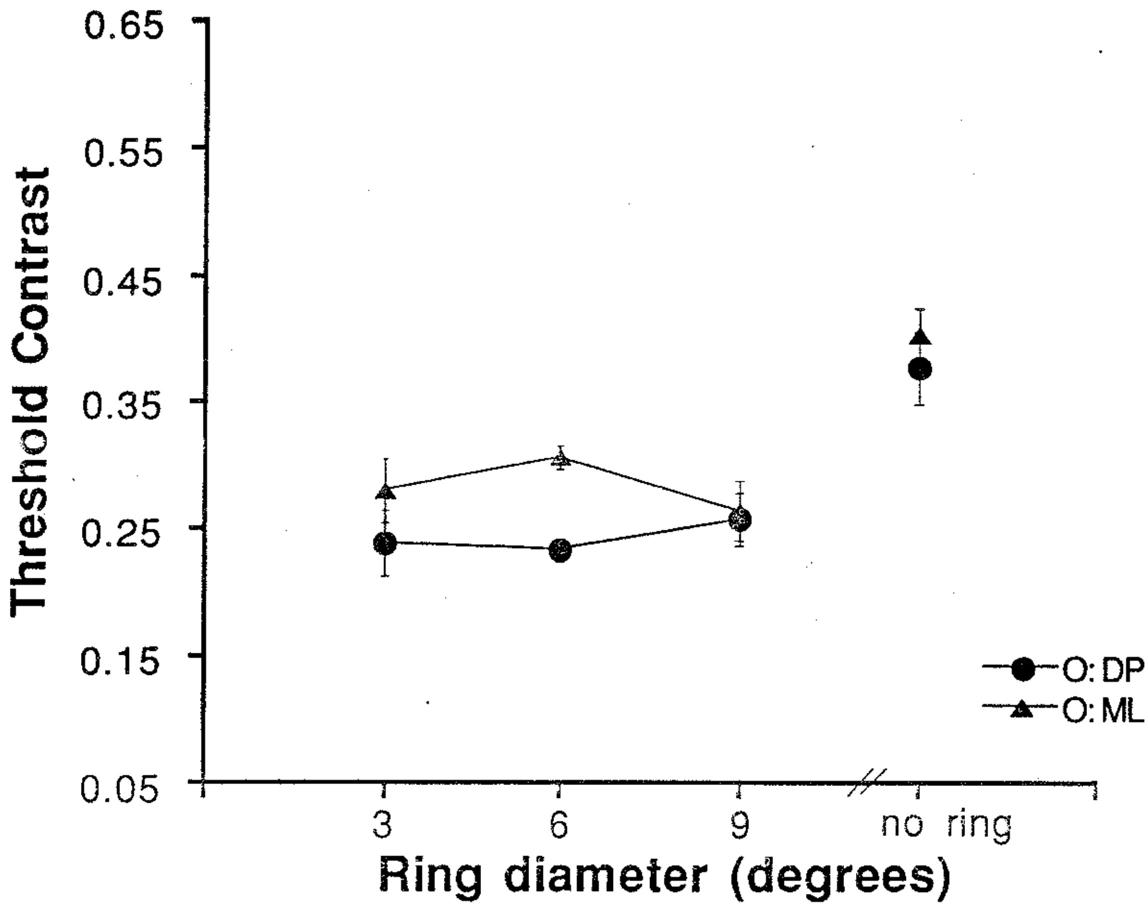


Figure 8.10. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding black ring diameter. The background luminance was **low** (0.011 fL). The target was presented presented for **500ms** following a **slow** ITI (4 sec.).

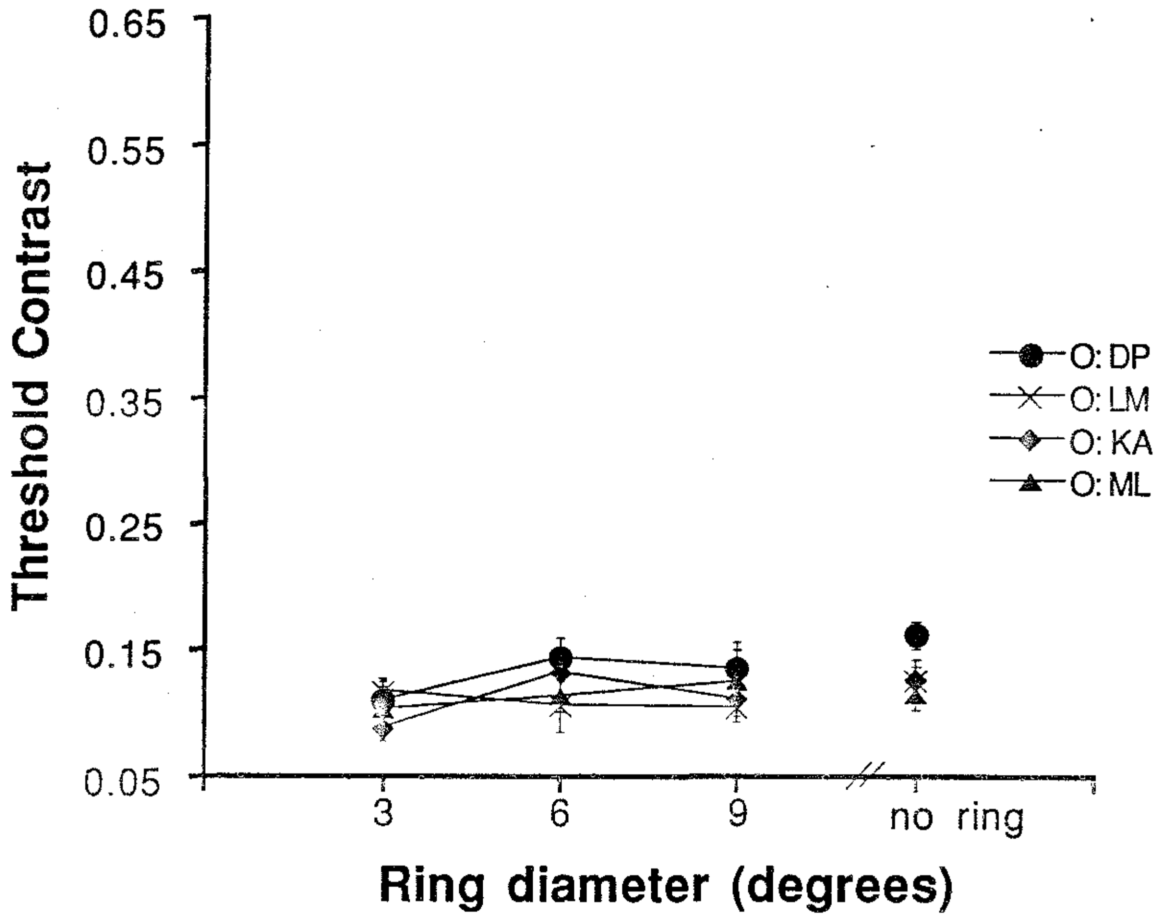


Figure 8.11. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding white ring diameter. The experiement was conducted under present ganzfeld conditions: the background luminance was 0.112 fL, and targets were presented for 500 ms following an ITI of 1 sec.

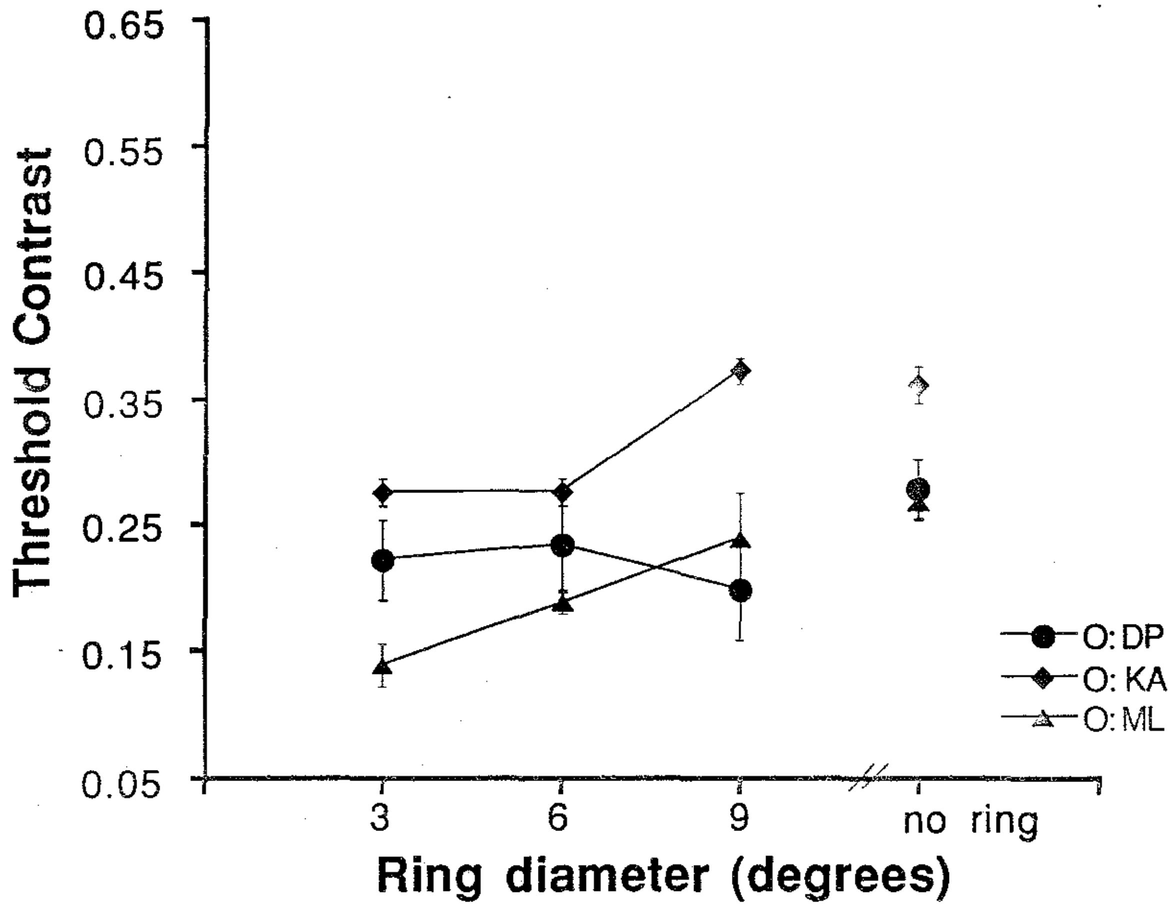


Figure 8.12. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding white ring diameter. The experiment was conducted under simulated original luminance and presentation conditions. The background luminance was 0.011 fL, and targets were presented for an unlimited duration following an ITI of 4 sec.

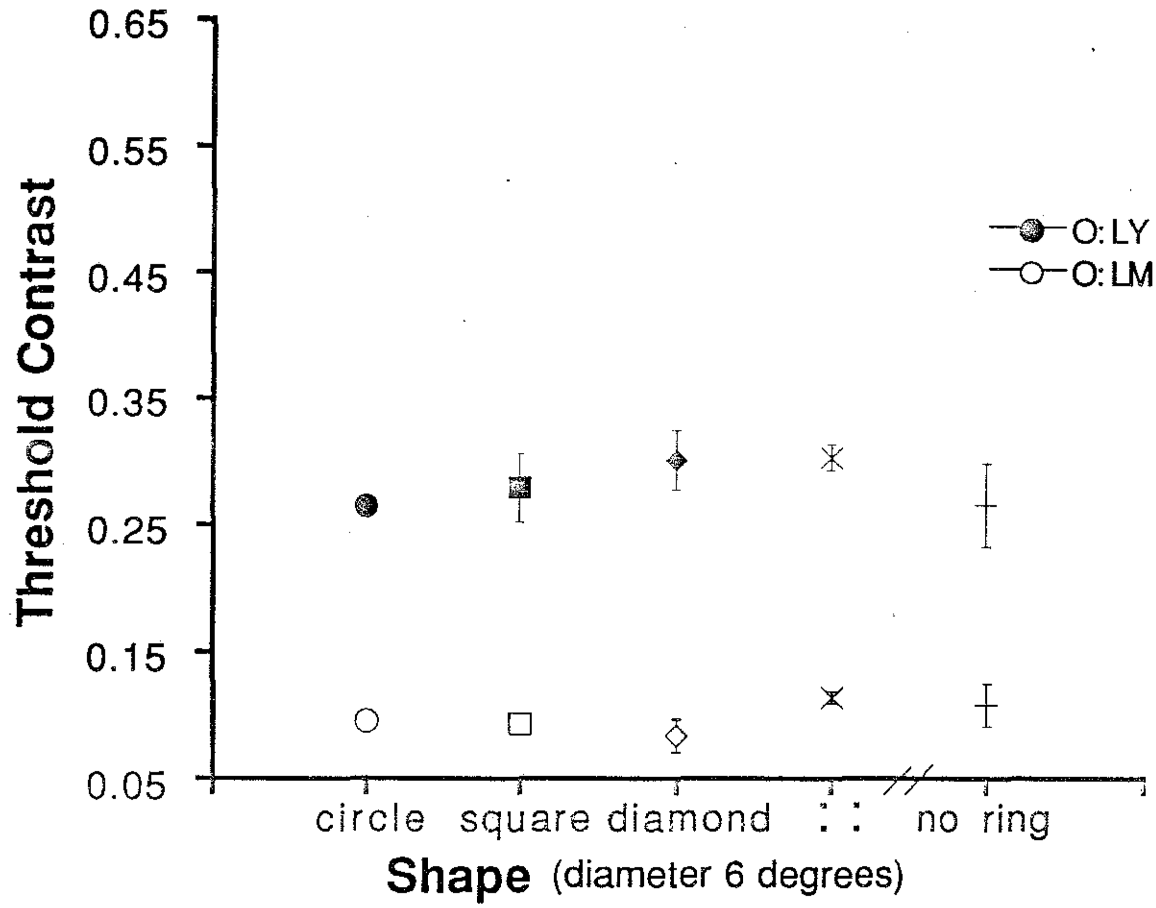


Figure 8.13. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding shape. Targets were centered within surrounding shapes with an equivalent width to that of the 6 degree diameter ring. The background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec.

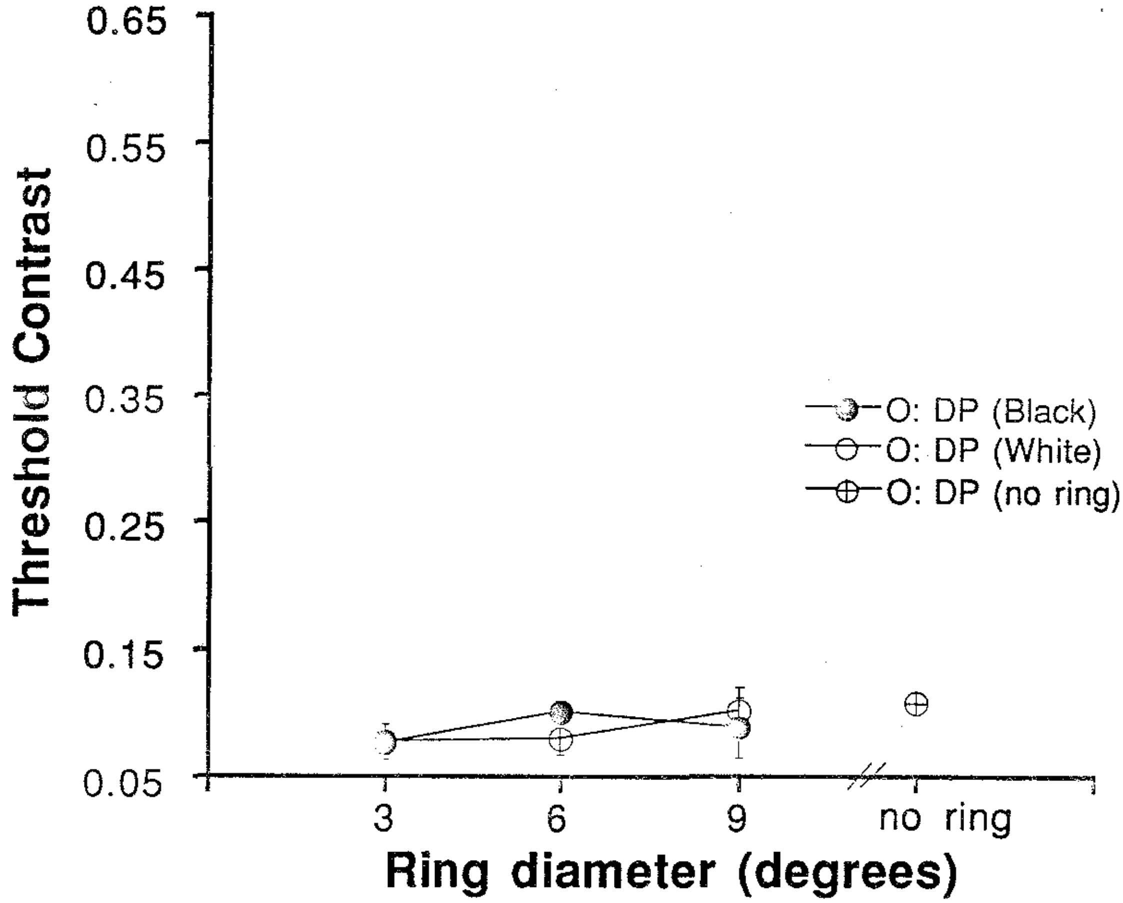


Figure 8.14. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding ring diameter and contrast. The background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec. Data are shown for observer DP.

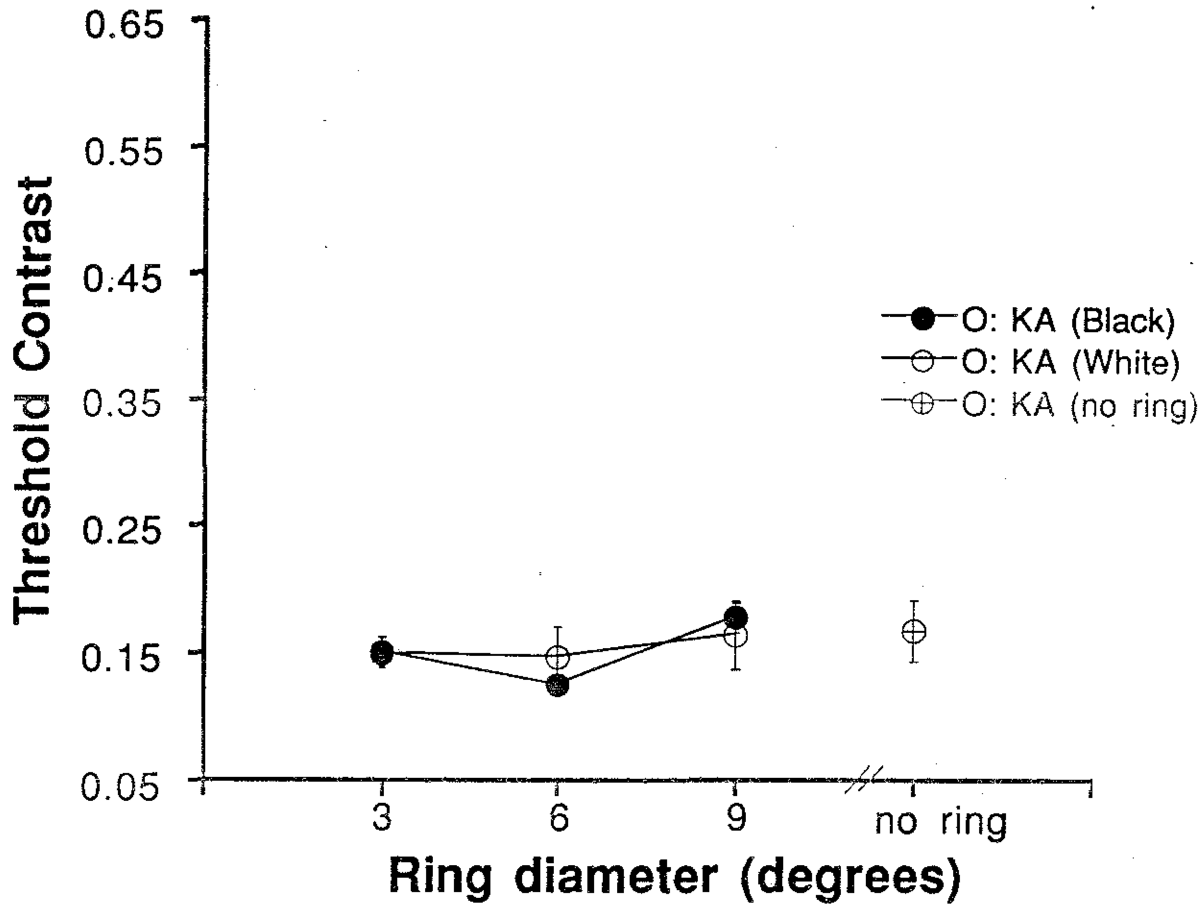


Figure 8.15. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding ring diameter and contrast. The background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec. Data are shown for observer KA.

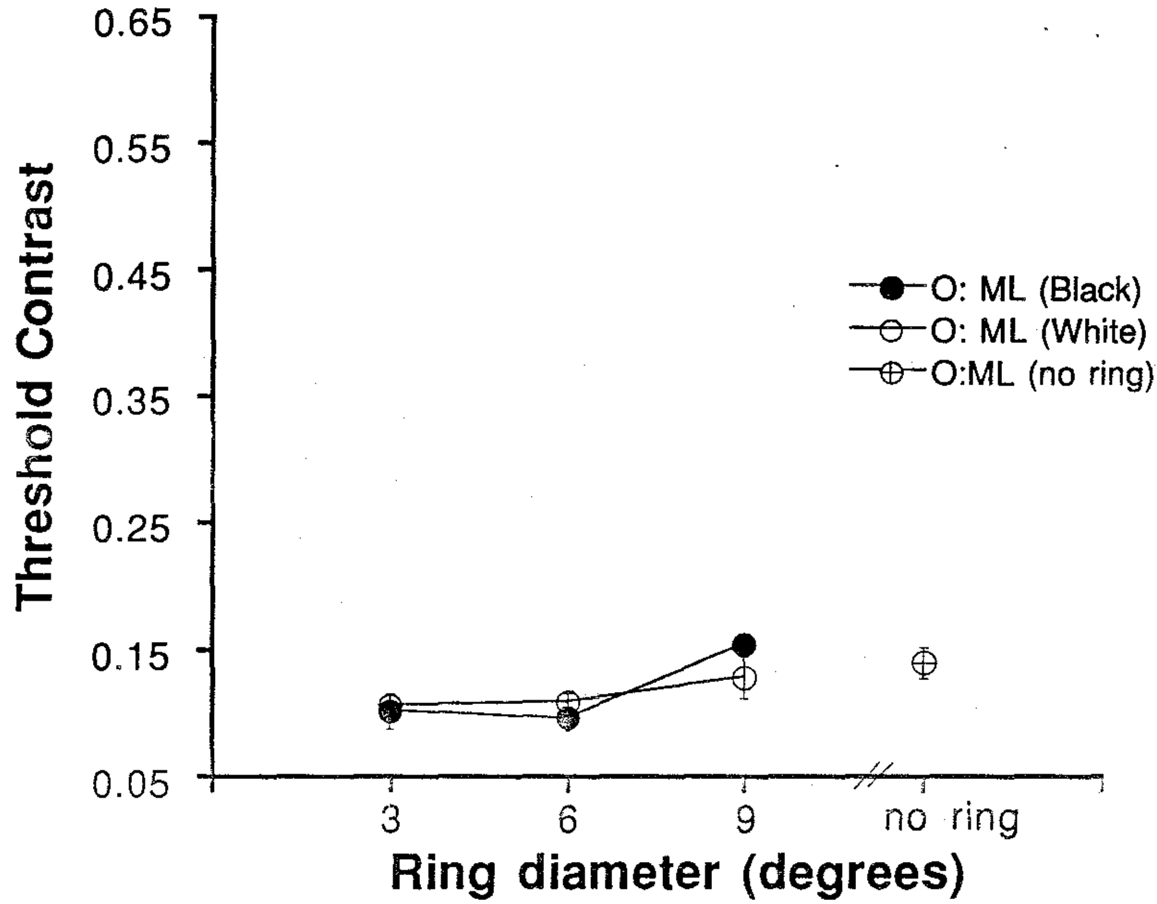


Figure 8.16. Contrast discrimination thresholds for a positive contrast target are plotted as a function of surrounding ring diameter and contrast. The background luminance was 0.112 fL. Targets were presented for 500 ms following an ITI of 1 sec. Data are shown for observer ML.

BIBLIOGRAPHY

Arend, L.E. Buehler, J.N., and Lockhead, G.R. "Difference Information In Brightness Perception." Perception & Psychophysics 9 (1971): 367-370.

Armstrong, J.D., Sorensen, J.A., Nelson, J.A., Tocino, I., Lester, P.D., Janes, J.O., Niklason, L.T., and Stanish, W. "Clinical Evaluation Of Unsharp Masking and Slit Scanning Techniques in Chest Radiography." Radiology 147 (May 1983): 351-356.

Baxter, B., Ravindra, H., and Normann, R.A. "Changes in Lesion Detectability Caused By Light Adaptation in Retinal Photoreceptors." Investigative Radiology 17(4) (July-August 1982): 394-401.

Bijl, P., Koenderink, J.J., Toet, A. "Visibility Of Blobs With a Gaussian Luminance Profile." Vision Research 29(4) (1989): 447-456.

Blum, H. "A New Model Of Global Brain Function." Perspectives in Biology and Medicine 10 (1967): 381-407.

Boynton, R.M. and Bush, W.R. "Recognition Of Forms Against a Complex Background." Journal of the Optical Society of America 46(9) (1956): 758-764.

Brogdon, B.G., Moseley, R.D., Kelsey, C.A., and Hallberg, J.R. "Perception Of Simulated Lung Lesions." Investigative Radiology 13(1) (Jan.-Feb. 1978): 12-15.

Burbeck, C.A. and Yap, Y.L. "Spatial Filter Selection In Large-scale Spatial-interval Discrimination." Vision Research 30(2) (1990): 262-272.

Campbell, F.W., Cooper, G.F., and Enroth-Cugell, C. "The Spatial Selectivity Of the Visual Cells Of the Cat." Journal of Physiology 203 (1969): 223-235.

Cole, B.L. and Jenkins, S.E. "The Effect Of Variability Of Background Elements On the Conspicuity Of Objects." Vision Research 24(3) (1984): 261-270.

Cohen, M.A. and Grossberg, S. "Neural Dynamics Of Brightness Perception: Features, Boundaries, Diffusion, and Resonance." Perception and Psychophysics 36(5) (1985): 428-456.

Coren, S. and Theodor, L.H. "Neural Interactions and Subjective Contours." Perception 6 (1977): 107-111.

Craik, K.J.W. and Zangwill, O.L. "Observations Relating To the Threshold Of a Small Figure Within the Contour Of a Closed-Line Figure." British Journal of Psychology 30 (1939): 139-150.

Cromartie, R. personal communication. May, 1991.

Cromartie, R. and Pizer, S.M. "Adaptive Contrast Enhancement Of Medical Images." Supplement to the Proceedings of the North Sea Conference on Biomedical Engineering (Nov. 1990).

Crowley, J.L. and Parker, A.C. "A Representation For Shape Based On Peaks and Rdges In the Difference Of a Low-pass Transform." IEEE Transactions, PAMI 6(2) (1984): 156-170.

Daffner, R.H. "Pseudofracture Of the Dens: Mach Bands." American Journal of Roentgenology 128 (April 1977): 607-612.

Daffner, R.H., Gehweiler, J.A., Rodan, B.A. "Subjective Contours and Illusory Roentgenographic Images." Applied Radiology (July-Aug. 1984): 95-98.

Day, R.H. and Jory, M.K. "Visual Psychophysics and Physiology." In Symposium In Honor of Lorrin Riggs On Visual Psychophysics and Physiology. eds. Armington, J.C., Krauskopf, J., and Wooten, B.R. (New York: Academic Press, 1978).

Eriksen, C.W. "Object Location In a Complex Perceptual Field." Journal of Experimental Psychology 45 (1953): 126-132.

Frei, W. "Image Enhancement by Histogram Hyperbolization." Computer Graphics and Image Processing 6 (1977): 286-294.

Fry, G.A. and Bartley, H. "The Effect Of One Border In the Visual Field Upon the Threshold Of Another." American Journal of Physiology 112 (1935): 414-421.

Gilchrist, A., Delman, S. and Jacobsen, A. "The Classification and Integration Of Edges As Critical To the Perception Of Reflectance and Illumination." Perception and Psychophysics 33(5) (1983): 425-436.

Gorea, A. and Julesz, B. "Context Superiority In a Detection Task With Line-element Stimuli: A Low-level Effect." Perception 19 (1990): 5-16.

Grossberg, S. and Mingolla, E. "Neural Dynamics Of Perceptual Grouping: Textures, Boundaries, and Emergent Segmentations." Perception and Psychophysics 38 (1985): 141-171.

Grossberg, S. and Todorovic, D. "Neural Dynamics Of 1-D and 2-D Brightness Perception: A Unified Model Of Classical and Recent Phenomena." Perception and Psychophysics 43 (1988): 241-277.

Horeman, H.W. "Inductive Brightness Depression As Influenced By Configurational Conditions." Vision Research 3 (1963): 121-130.

Jaffe, C.C. Medical Imaging, Vision, and Visual Psychophysics. Medical Radiography and Photography, vol 60, no. 1. Eastman Kodak Company,1984.

Jain, A.K. Fundamentals of Digital Image Processing. Englewood Cliffs, NJ: Prentice Hall, 1989.

Jameson, D. and Hurvich, L.M. "Complexities Of Perceived Brightness." Science 133 (1961): 74-179.

Jenkins, S.E. and Cole, B.L. "The Effect Of the Density of Background Elements On the Conspicuity Of Objects." Vision Research 22 (1982): 1241-1252.

Johnson, G.A., Danieley, N., and Ravin, C.E. "Processing Alternatives For Digital Chest Imaging." Radiologic Clinics of North America 23(2) (June 1985): 335-340.

Katz, M.S. "Feedback and Accuracy Of Target Positioning In a Homogeneous Visual Field." American Journal of Psychology 80 (1967): 405-410.

Katz, M.S., Metlay, W., and Cirincione, P.A. "Effects Of Stimulus and Field Size On the Accuracy Of Orientation In the Homogeneous Environment." Perceptual and Motor Skills 20 (1965): 167-172.

Kelsey, C.A., Moseley, R.D., Brogdon, B.G., Bhave, D.G. and Hallberg, J. "Effect Of Size and Position On Chest Lesion Detection." American Journal of Roentgenology 129 (Aug. 1977): 205-208.

Kienker, P.K., Sejnowski, T.J., Hinton, G.E., and Schumacher, L.E. "Separating Figure From Ground With a Parallel Network." Perception 15 (1986): 197-216.

Klymenko, V., Pizer, S.M. and Johnston, R.E. "Visual Psychophysics and Medical Imaging: Nonparametric Adaptive Method For Rapid Threshold Estimation In Sensitivity Experiments." IEEE Transactions on Medical Imaging 4 (Dec. 1990): 353-365.

Koenderink, J.J. "The Brain a Geometry Engine, Psychol. Research, (1990).

Kundel, H.L. and Revesz, G. "Lesion Conspicuity, Structured Noise, and Film Reader Error." American Journal of Roentgenology 126 (1976): 1233-1238.

Land, E.H. "The Retinex Theory Of Color Vision." Scientific American 237 (1977): 108-121.

Lane, E.J., Proto, A.V., and Philips, T.W. "Mach Bands and Density Perception." Radiology 121 (Oct. 1976): 9-17.

Levitt, H. "Adaptive Testing In Audiology." Scandanavian Audiology Supplement 6 (1978): 241-291.

Leyton, M. "Perceptual Organization As Nested Control." Biological Cybernetics 51 (1984): 141-153.

Leibowitz, H., Mote, F.A., and Thurlow, W.R. "Simultaneous Contrast As a Function Of Separation Between Test and Inducing Fields." Journal of Experimental Psychology 46(6) (1953): 453-456.

Loo, L.D., Doi, K., and Metz, C.E. "Investigation Of Basic Imaging Properties In Digital Radiography. 4. Effects Of Unsharp Masking On the Detectability Of Simple Patterns." Medical Physics 12(2) (Mar-April 1985): 209-214.

Marr, D. and Nishihara, H.K. "Representation and Recognition Of the Spatial Organization Of Three-Dimensional Shapes." Proceedings of the Royal Society of London B200 (1978): 169-294.

Maxwell, S.E. and Delaney, H.D. Desiging Experiments and Analyzing Data. Belmont, California: Wadsworth Publishing Company, 1990.

McAdams, H.P., Johnson, G.A., Suddarth, S.A., and Ravin, C.E. "Histogram-directed Processing Of Digitial Chest Images." Investigative Radiology 21 (March 1986): 253-259.

Metz, C. "Basic Principles Of ROC Analysis." Seminars in Nuclear Medicaine 8(4) (Oct. 1978): 283-298.

Miller, J.W. and Hall, R.J. "Accuracy Of Orientation and Positioning In Homogeneous Visual Fields." Aerospace Medicine 34 (April 1963): 337-341.

Morgan, R.H. "Visual Perception in Fluoroscopy and Radiography." Radiology 86 (March 1966): 403-416.

Myers, K.J. and Barrett, H.H. "Addition Of a Channel Mechanism To the Ideal-Observer Model." Journal of the Optical Society of America 4(12) (Dec. 1987): 2447-2457.

Peli, T. and Lim, J.S. "Adaptive Filtering for Image Enhancement." Optical Engineering 21(1) (1982): 108-112.

Perona, P. and Malik, J. "Scale-Space and Edge Detection Using Anisotropic Diffusion." Report No. UCB/CSD 88/483. Computer Science Division (EECS) University of California, Berkely, California (December 1988).Pizer, S.M. "An Automatic Intensity Mapping For the Display Of CT Scans and Other Images." Medical Image Processing: Proceedings of the VIIth International Meeting on Information Processing in Medical Imaging. Stanford University (1981): 276-309.

Pizer, S.M. "Psychovisual Issues In the Display of Medical Images." In Pictorial Information Systems in Medicine , ed. K.H. Hoehne, 211-234. Berlin: Springer-Verlag, 1985.

Pizer, S.M., Amburn, E.P., Austin, J.D., Cromartie, R., Geselowitz, A., ter Haar Romeny, B., Zimmerman, J.B., and Zuiderveld, K. "Adaptive Histogram Equalization and Its Variations." Computer Vision, Graphics, and Image Processing 39 (1987): 355-368.

Pizer, S.M., Coggins, J.M., and Burbeck, C.A. "Formation Of Image Objects In Human Vision." CAR Proceedings. (Berlin: Springer-Verlag, 1991).

Pizer, S.M. and ter Haar Romeny, B.M. "Fundamental Properties Of Medical Image Perception." Journal of Digital Imaging 4(1) (February 1991): 1-20.

Plessis, B., Goldberg, M., Dillon, R., Tombaugh, J., Robertson, J., Belanger, G., and Hickey, N. "Context-Dependent Enhancements For Radiological Images." Journal of Digital Imaging 2(2) (May 1989): 114-122.

Puff, D.T., Klymenko, V., Johnston, R.E., Burbeck, C.A., and Pizer, S.M. "Long-Distance Context-Effects On Contrast Detection In a Ganzfeld." 1991 Meeting of the Association for Research in Vision and Opthalmology.

Ratliff, F. "Contour and Contrast." Scientific American 226 (June 1972): 91-101.

Rosenman, J., Roe, C.A., Cromartie, R., Muller, K.E., and Pizer, S.M. "Portal Film Enhancement: Technique and Clinical Utility." (to be submitted) International Journal of Radiation Oncology, Biology, and Physics. 1991.

Sherrier, R.H., Chiles, C., Wilkinson, W.E., Johnson, G.A. and Ravin, C.E. "Effects Of Image Processing On Nodule Detection Rates In Digitized Chest Radiographs: ROC Study Of Observer Performance." Radiology 166 (1988): 447-450.

Sherrier, R.H. and Johnson, G.A. "Regionally Adaptive Histogram Equalization Of the Chest." IEEE Transactions on Medical Imaging MI-6(1) (March 1987): 1-7.

Sorensen, J.A., Niklason, L.T. and Nelson, J.A. "Photographic Unsharp Masking In Chest Radiography." Investigative Radiology 16 (July-Aug 1981): 281-288.

van der Wildt, G.J. and Waarts, R.G. "Contrast Detection and Its Dependence On the Presence Of Edges and Lines In the Stimulus Field." Vision Research 23(8) (1983): 821-830.

Weisstein, N. and Harris, C.S. "Visual Detection Of Line Segments: An Object-Superiority Effect." Science 186 (Nov. 1977): 752-755.

Wildman, K.N. "Visual Sensitivity At an Edge." Vision Research 14 (1974): 749-755.

Young, R.A. "The Gaussian Derivative Model For Spatial Vision: I. Retinal Mechanisms." Spatial Vision 2 (1987): 273-293.

Youniss, J. and Calvin, A.D. "The Enclosing Contour Effect." Perceptual Motor Skills 13 (1961): 75-81.