

Appendix A: ARVO Paper

Binocular Viewing Mode Affects Spatio-temporal Contrast Threshold

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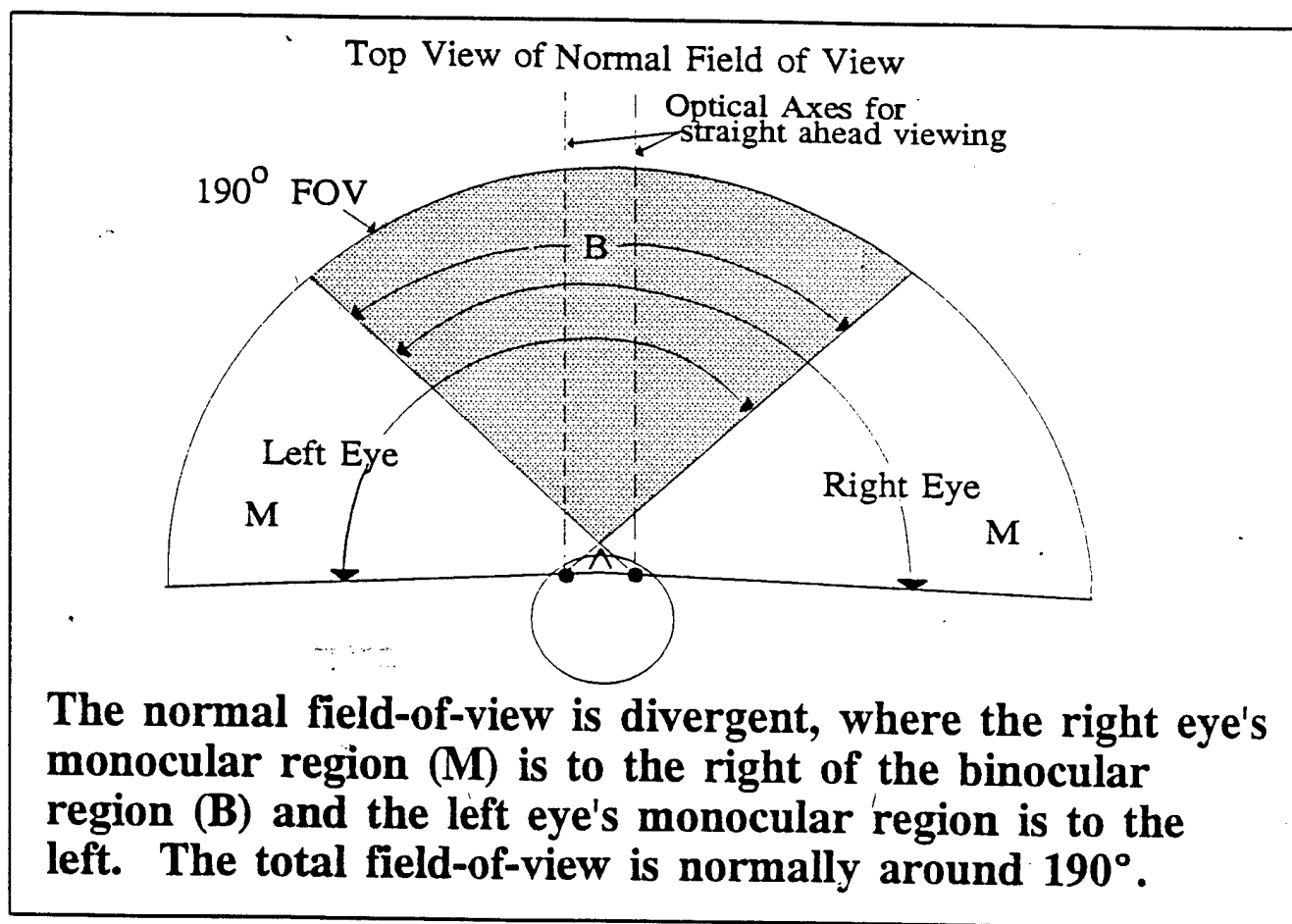
CONTRIBUTION STATEMENT A

Approved for public release  
Distribution Unlimited

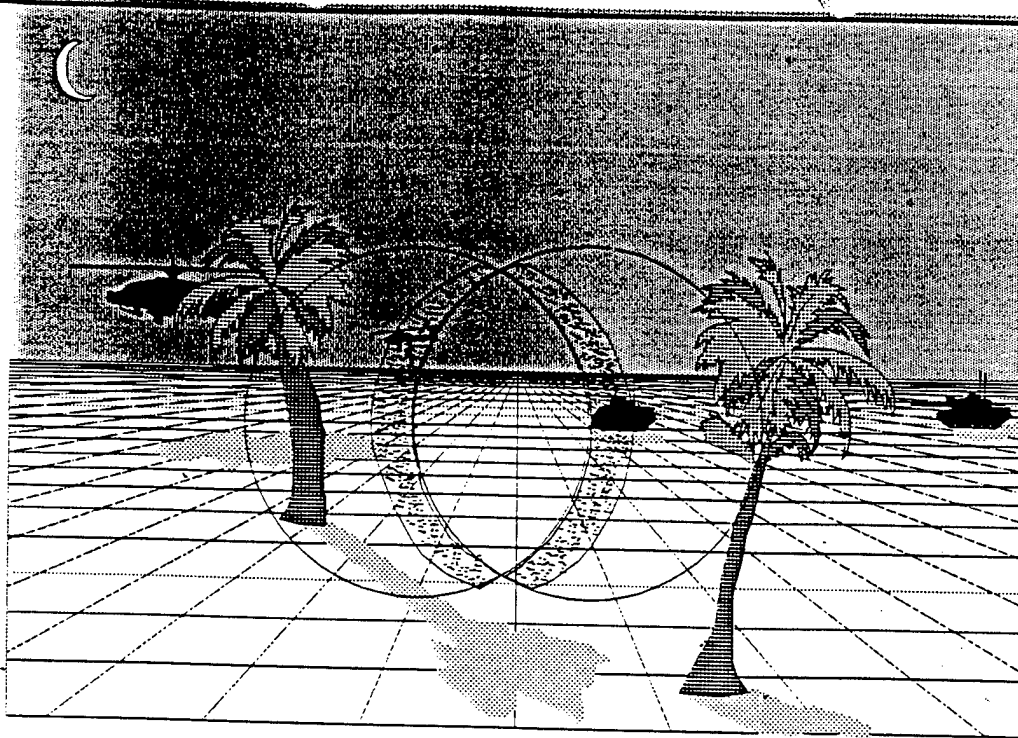
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# Purpose

The normal binocular field-of-view is indicated below.



If the field-of-view is reduced such as may occur in a helmet mounted display, a number of factors change, as shown below.



A helicopter pilot's view of the visual world using an *HMD in partial binocular overlap display mode*. The helicopter in the left visual field and the armored personnel carrier in the right visual field are each in monocular regions near the *Monocular/Binocular border*. If the right eye is viewing the circular region containing the armored personnel carrier, the display mode is *Divergent*. If instead, the left eye is viewing this region, the display mode is *Convergent*.

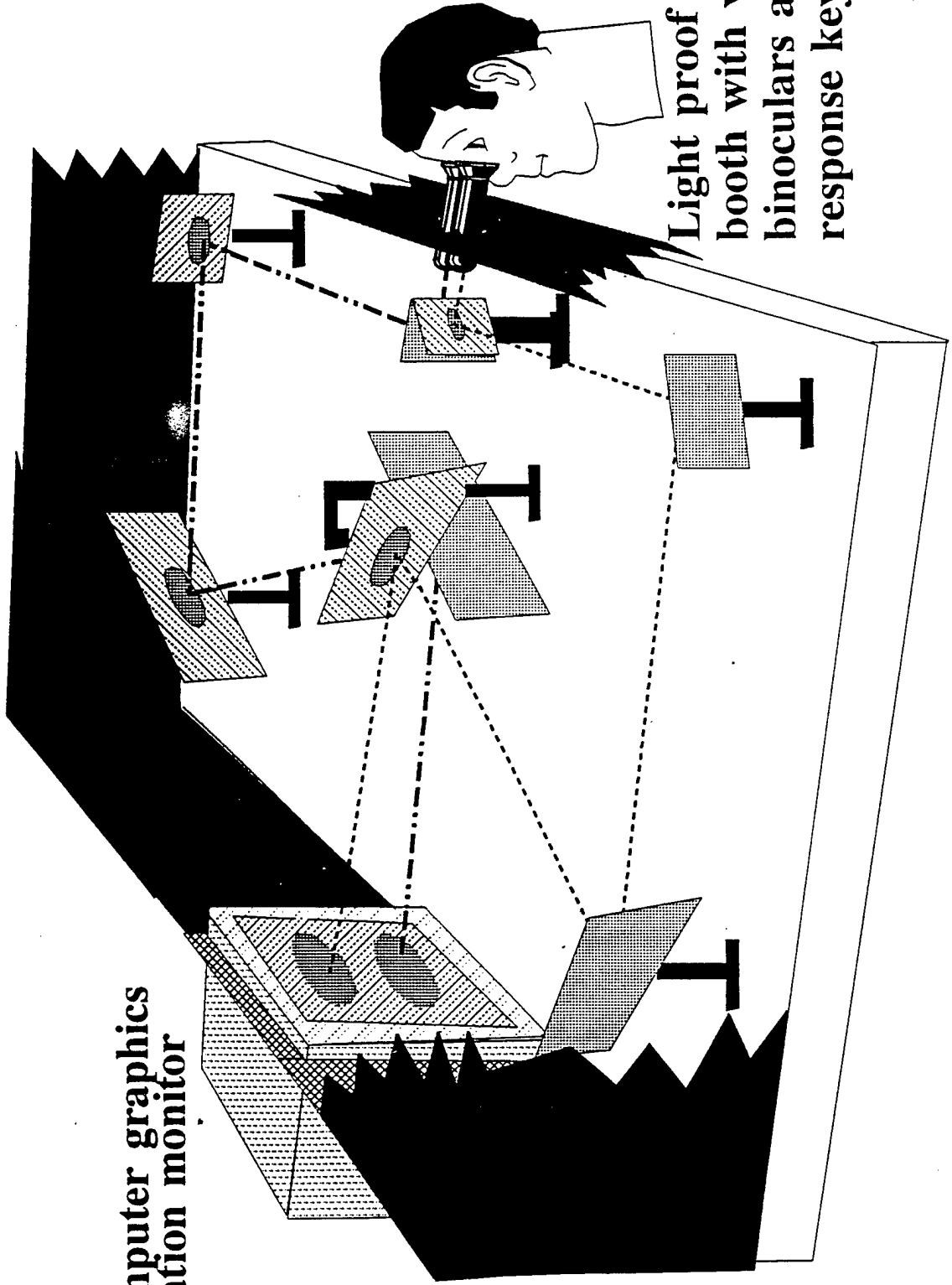
To increase the available field-of-view, the display may be presented in a *partial binocular overlap display mode*. (Convergent or divergent) as opposed to a *complete binocular overlap display mode*, where both eyes see the same image.

We quantified *changes in visual sensitivity across the field of view* for these *display modes* by measuring contrast thresholds of various probes in various positions.

# EQUIPMENT

## Optical table mirror configuration

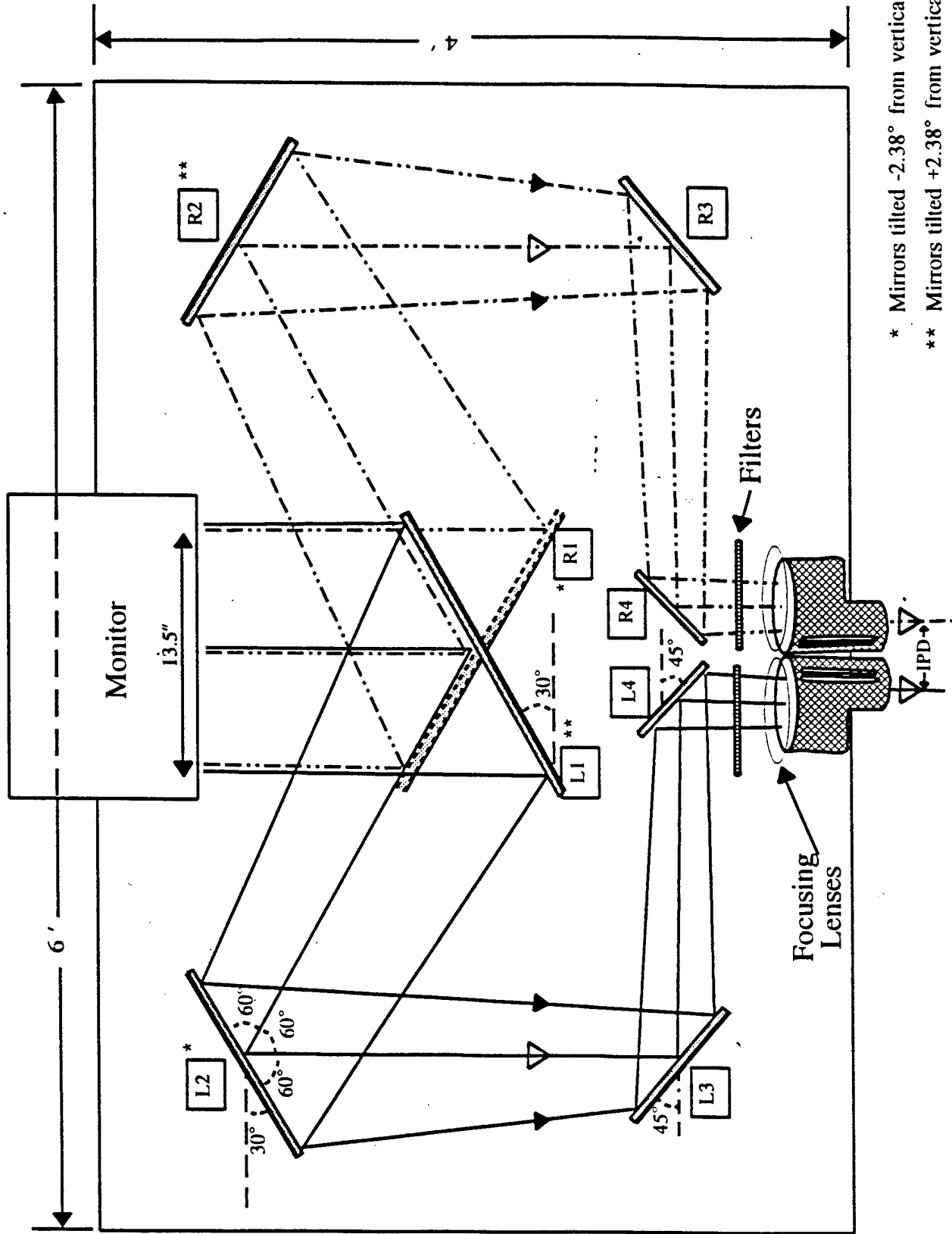
HP computer graphics workstation monitor



Light proof subject booth with viewing binoculars and response keypad

4/14/6  
S. 1950

# Details of Optical Table Configuration



\* Mirrors tilted  $-2.38^\circ$  from vertical

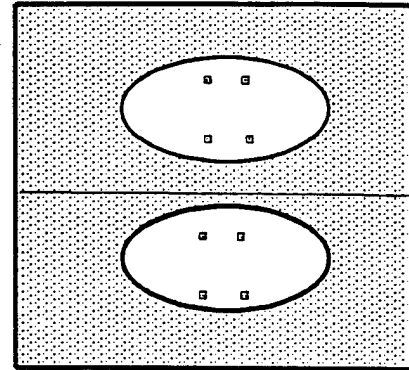
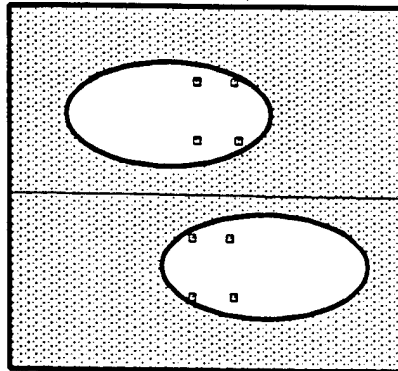
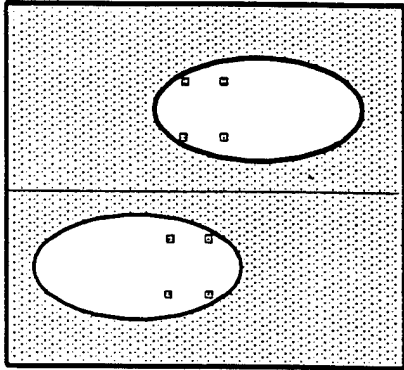
\*\* Mirrors tilted  $+2.38^\circ$  from vertical

# Display Modes

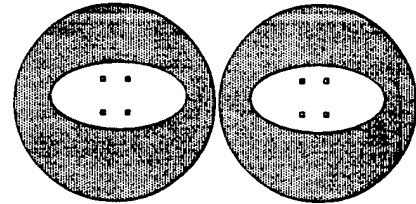
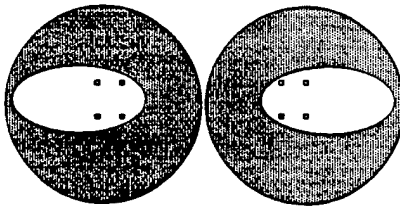
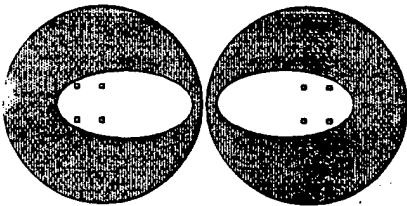
Convergent  
Display Mode

Divergent  
Display Mode

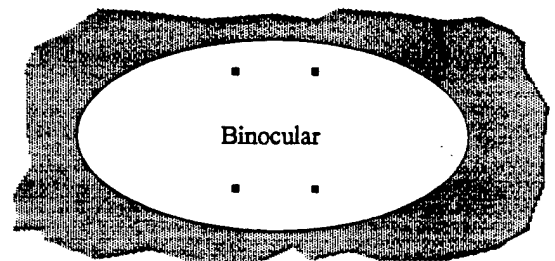
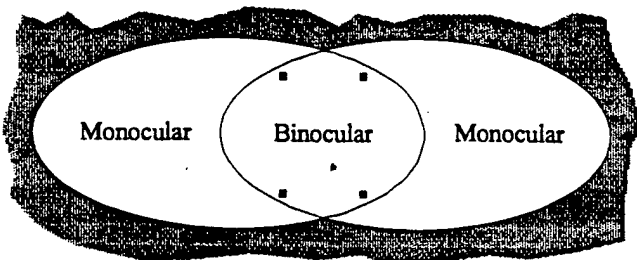
Complete Overlap  
Display Mode



Elliptical monocular  
fields on the monitor

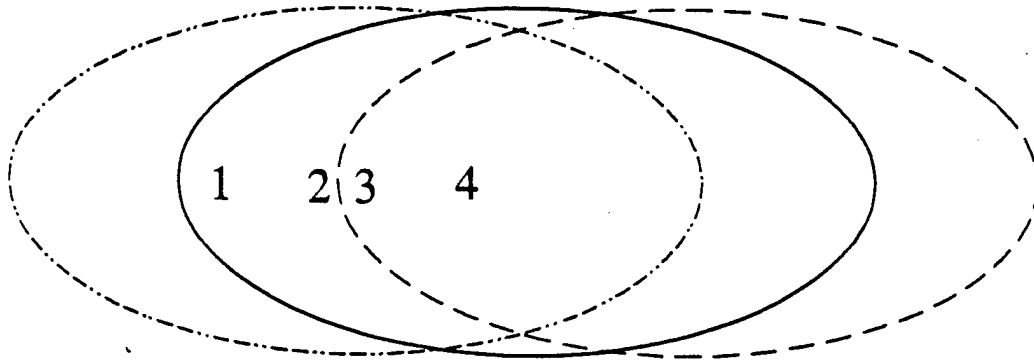


Through the  
Binoculars

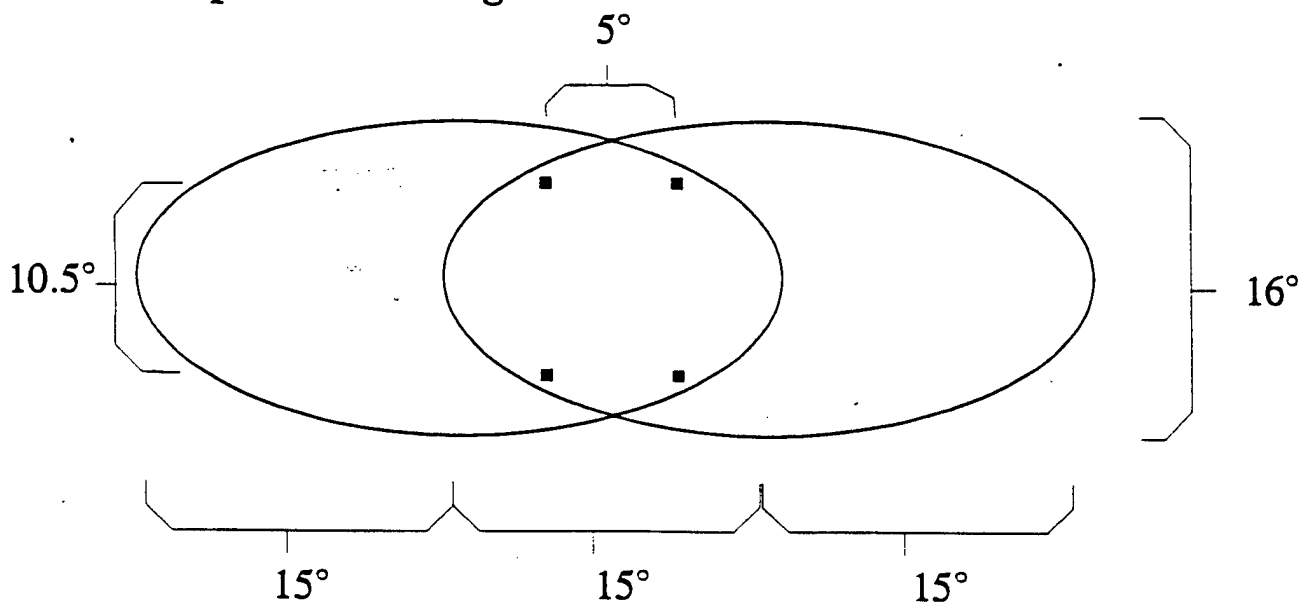


Field-of-view as seen  
by the observer

Note: small black squares are fusion locks

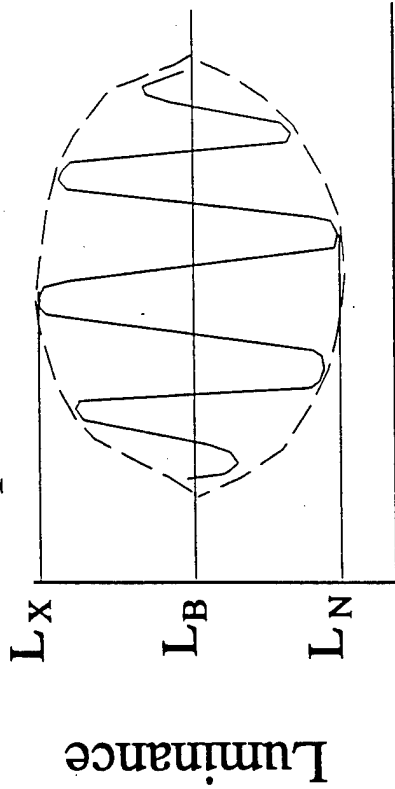


The relative positions of the elliptical monocular fields and the four probe positions are shown superimposed. Both eyes see the ellipse with the solid line in the *complete overlap display mode*. In the *divergent display mode*, the right eye sees the dashed ellipse on the right, and the left eye sees the dotted ellipse on the left. Conversely, in the *convergent mode*, the right eye sees the dotted ellipse on the left, and the left eye sees the dashed ellipse on the right.

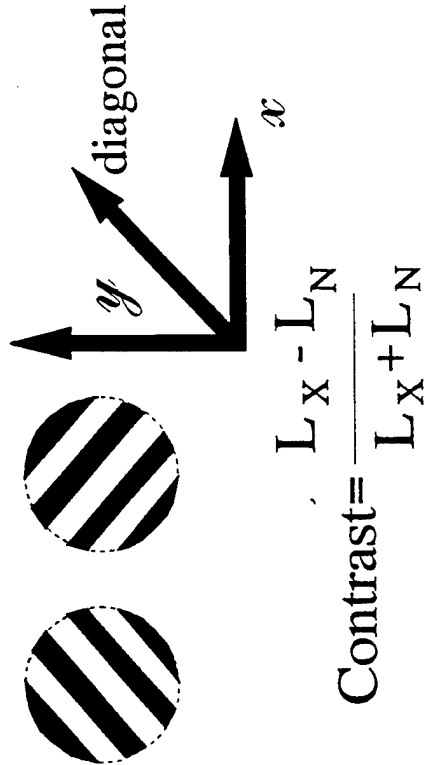


The visual dimensions in degrees of visual angle are given to the right and below the overlapping monocular fields. The distances between fusion locks are given above and to the left. Monocular fields were 2 fL against a black background.

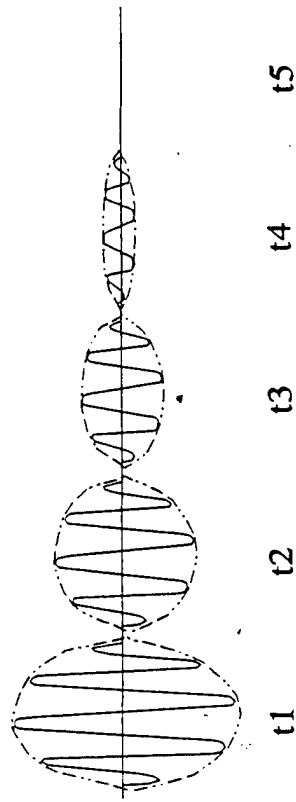
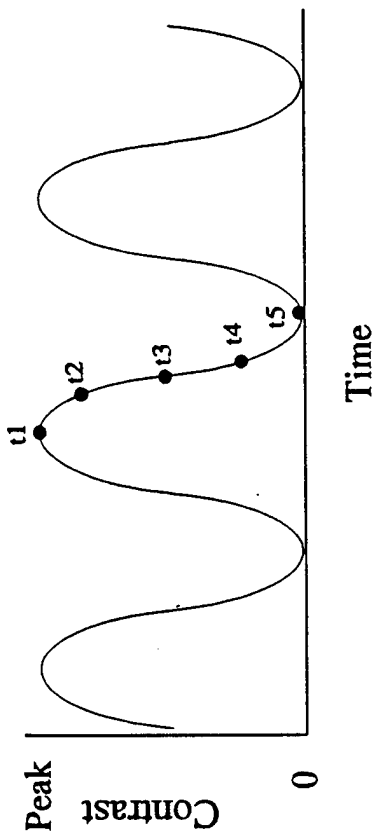
### Spatial Modulation



### Diagonal Spatial Cross Section



### Temporal Modulation



Spatial cross section at five points in time.

## Procedure













1. Eye exam
2. Equipment calibrated to subject's IPD.
3. Method of adjustment used to set contrast threshold of probe for determining orientation.

# Design

All stimulus combinations were tested. These included: 3 display modes x 4 probe positions x 16 types of probe stimuli (4 spatial frequencies x 4 temporal frequencies). A single probe spatial frequency and position were run in a session, which included the three display modes x four temporal frequencies x three blocks. Right and left versions of each position were averaged. The following number of subjects were run in each position x spatial frequency combination.

	<u>cpd</u>			
	8.48	4.24	2.12	1.07
1	17	22	23	18
2	23	26	27	20
3	25	26	25	17
4	17	19	21	15

# DISPLAY MODE

		Convergent	Divergent	Complete Overlap
PROBE POSITION	1	 MN	 MN	 B
	2	 MA	 MA	 B
	3	 BA	 BA	 B
	4	 BN	 BN	 B

Monocular fields



Left Eye



Right Eye

Probe Positions

M = Monocular region

B = Binocular region

Distance of probe to

monocular/binocular border

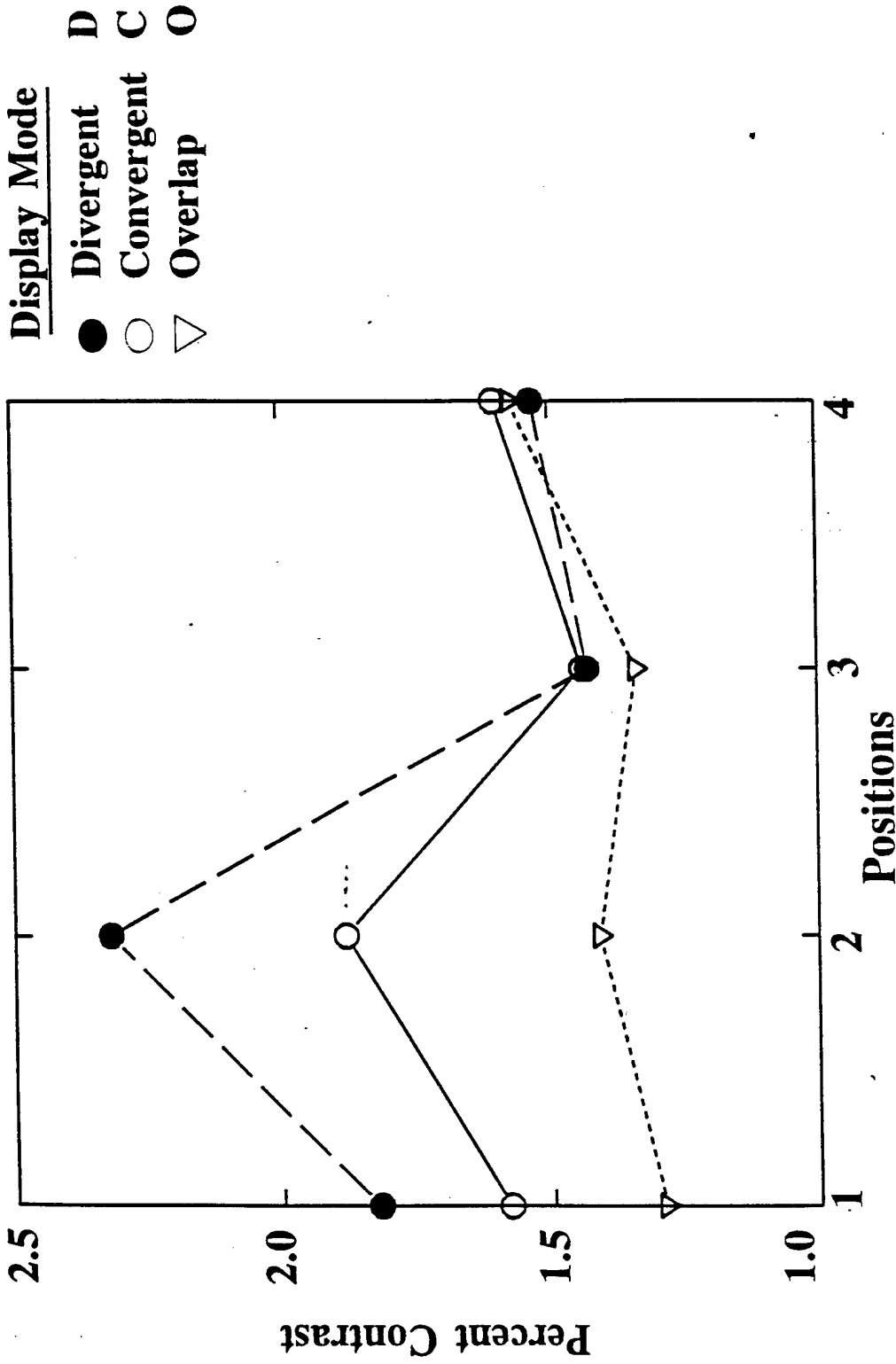
N = Nonadjacent,  $2.03^\circ$

A = Adjacent,  $0.08^\circ$

Relative locations of four probe  positions (right side and left side versions), in the three display modes.

# **Contrast Threshold Results**

# 8.48 cpd 0 Hz



Display Mode

- Divergent
- Convergent
- △ Overlap

t-test

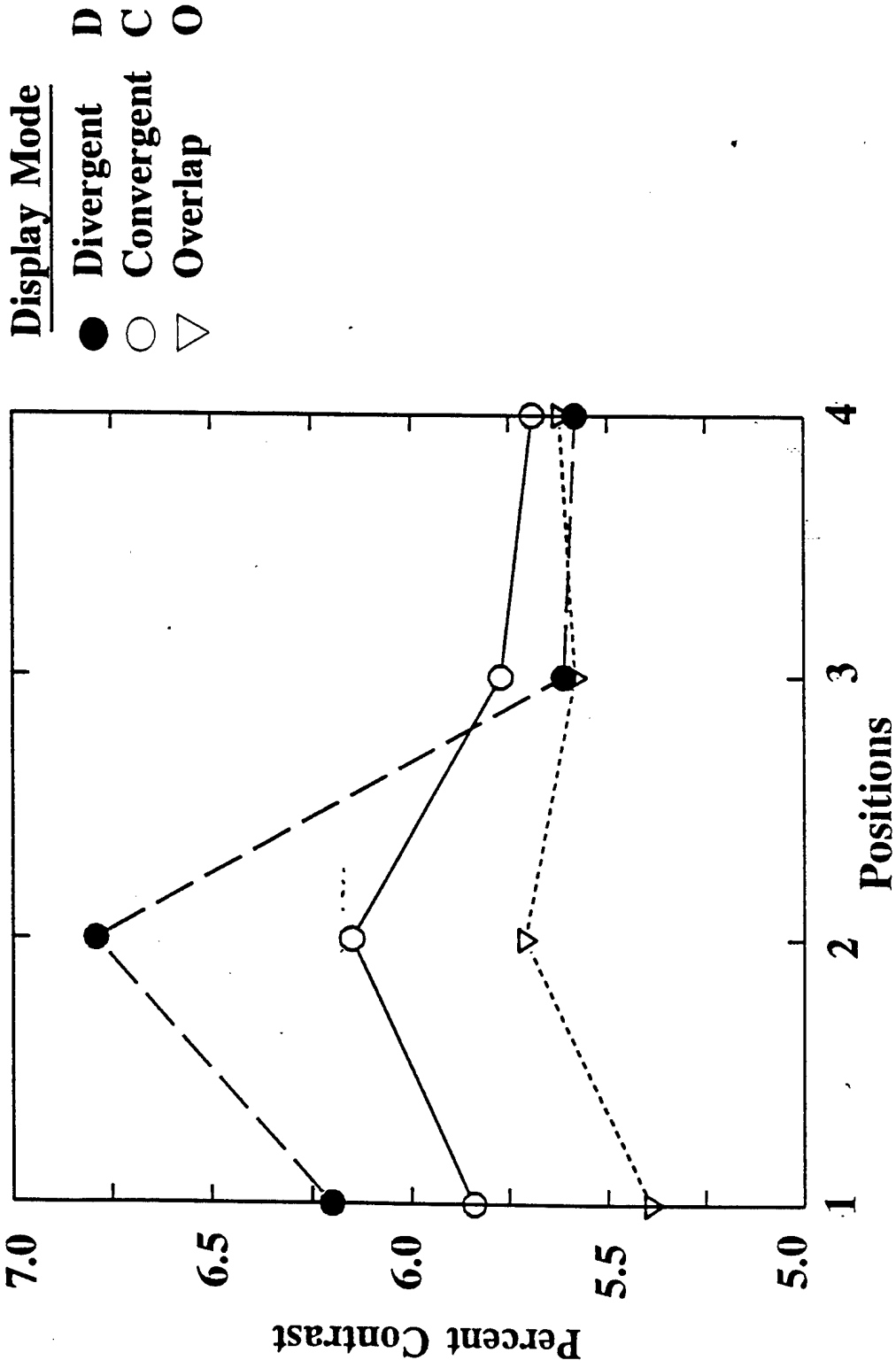
C v D	.05	.005	NS	NS
O v C	.01	*	.05	NS
O v D	.0005	*	.05	NS

p <

\* = p < .0001



# 8.48 cpd 15 Hz



**Display Mode**  
**● Divergent** **D**  
**○ Convergent** **C**  
**▽ Overlap** **O**

**t-test**

**C v D**  
**O v C**  
**O v D**

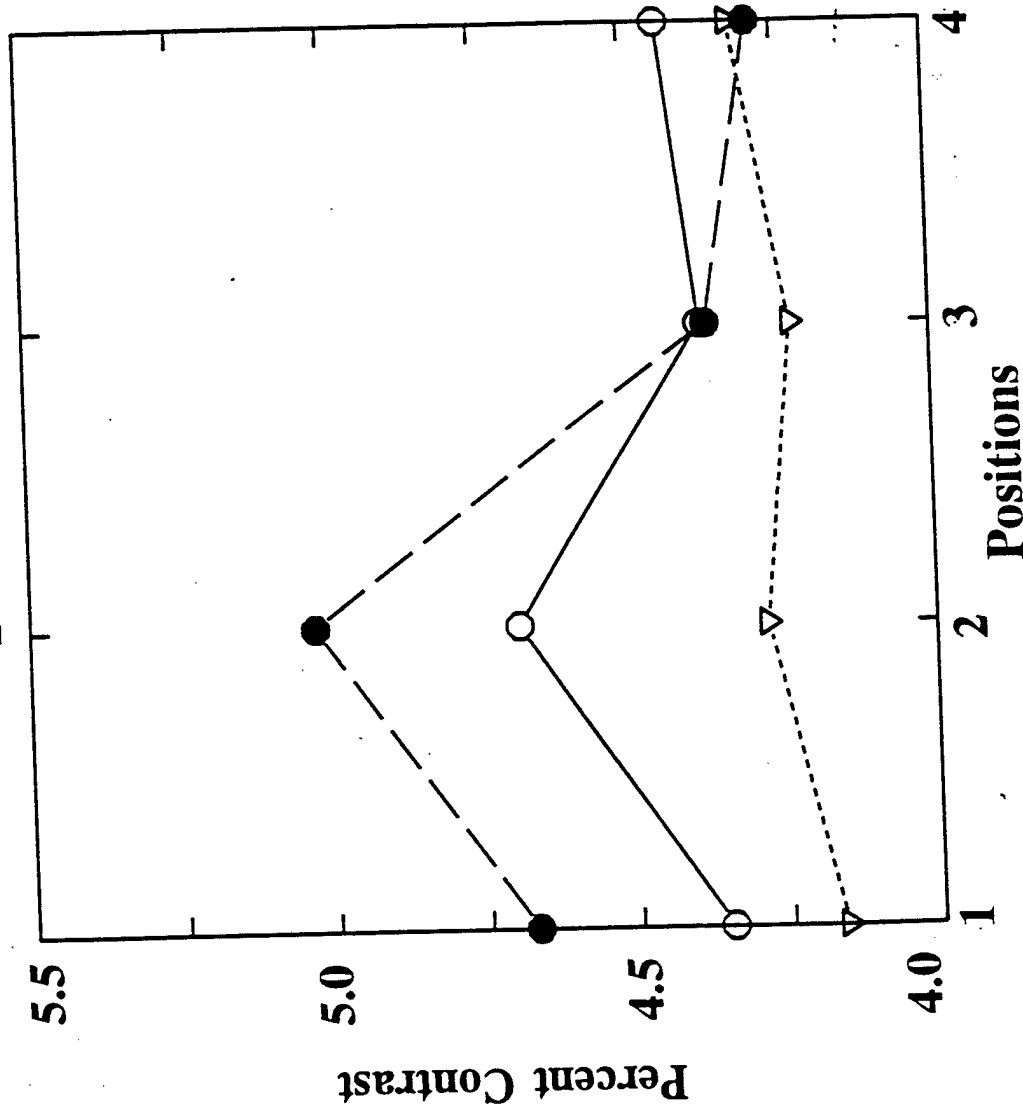
.025	.00025	NS	NS
.01	*	.01	NS
*	*	NS	NS

**p <**

**\* = p < .0001**

# 8.48 cpd 7.5 Hz

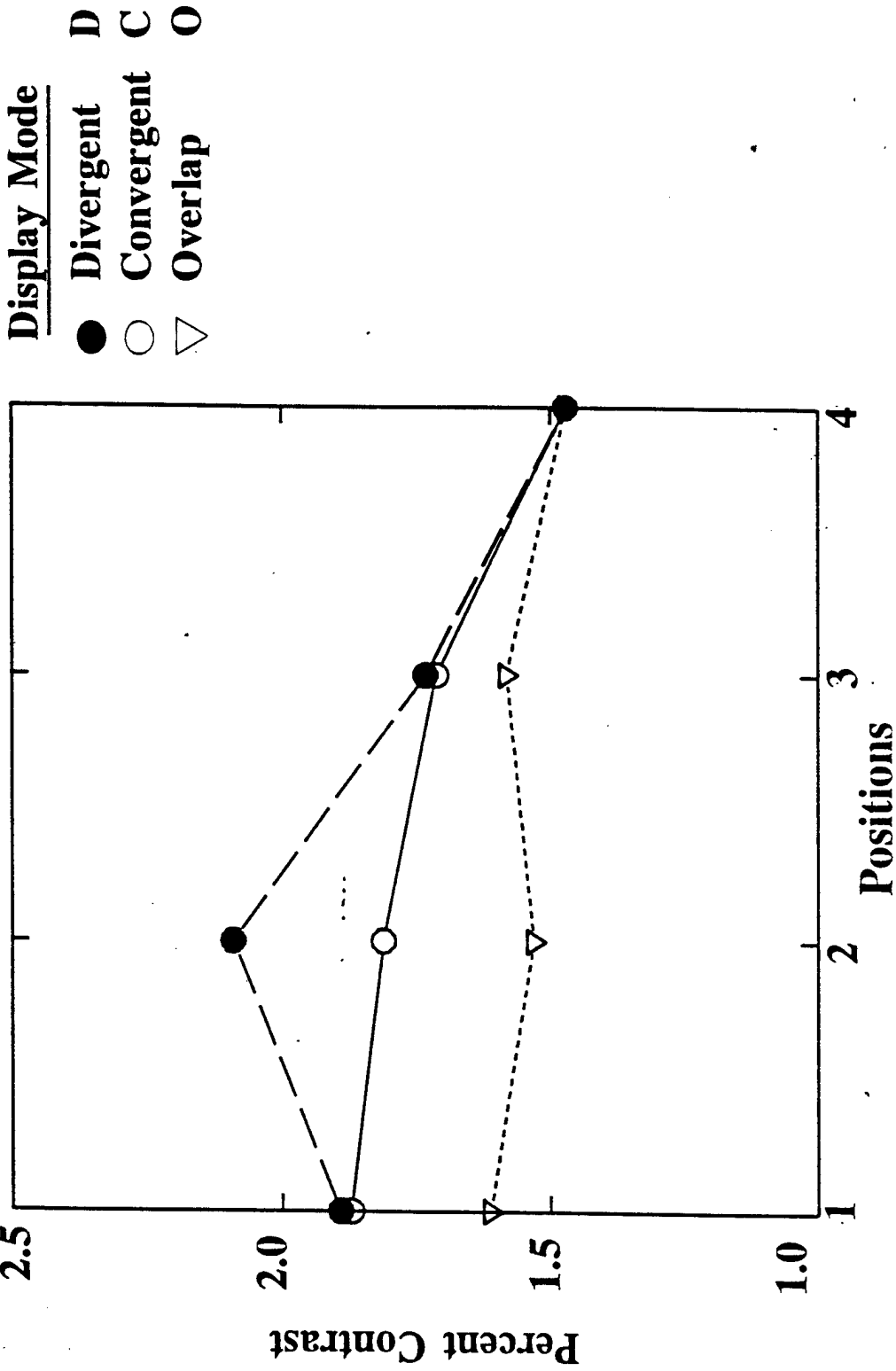
Display Mode  
**D** Divergent  
**C** Convergent  
**O** Overlap



\* =  $p < .0001$

t-test	p <		
C v D	.01	.0025	NS
O v C	.05	*	.025
O v D	.0005	*	.025

# 4.24 cpd 0 Hz



t-test

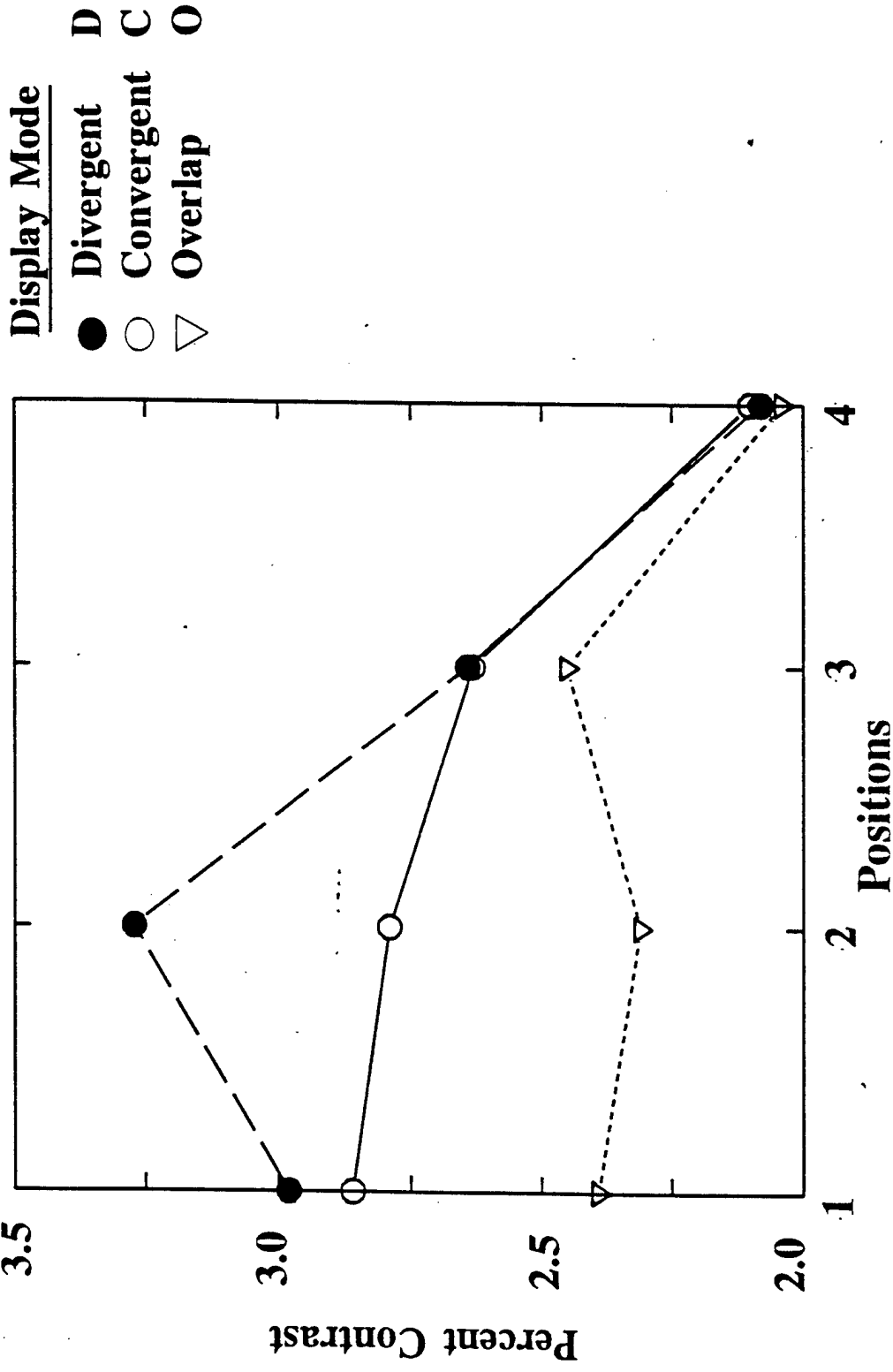
C v D				
O v C				
O v D				

NS	.025	NS	NS
.00025	*	.025	NS
.0025	*	.01	NS

p <

\* = p < .0001

# 4.24 cpd 15 Hz



Display Mode

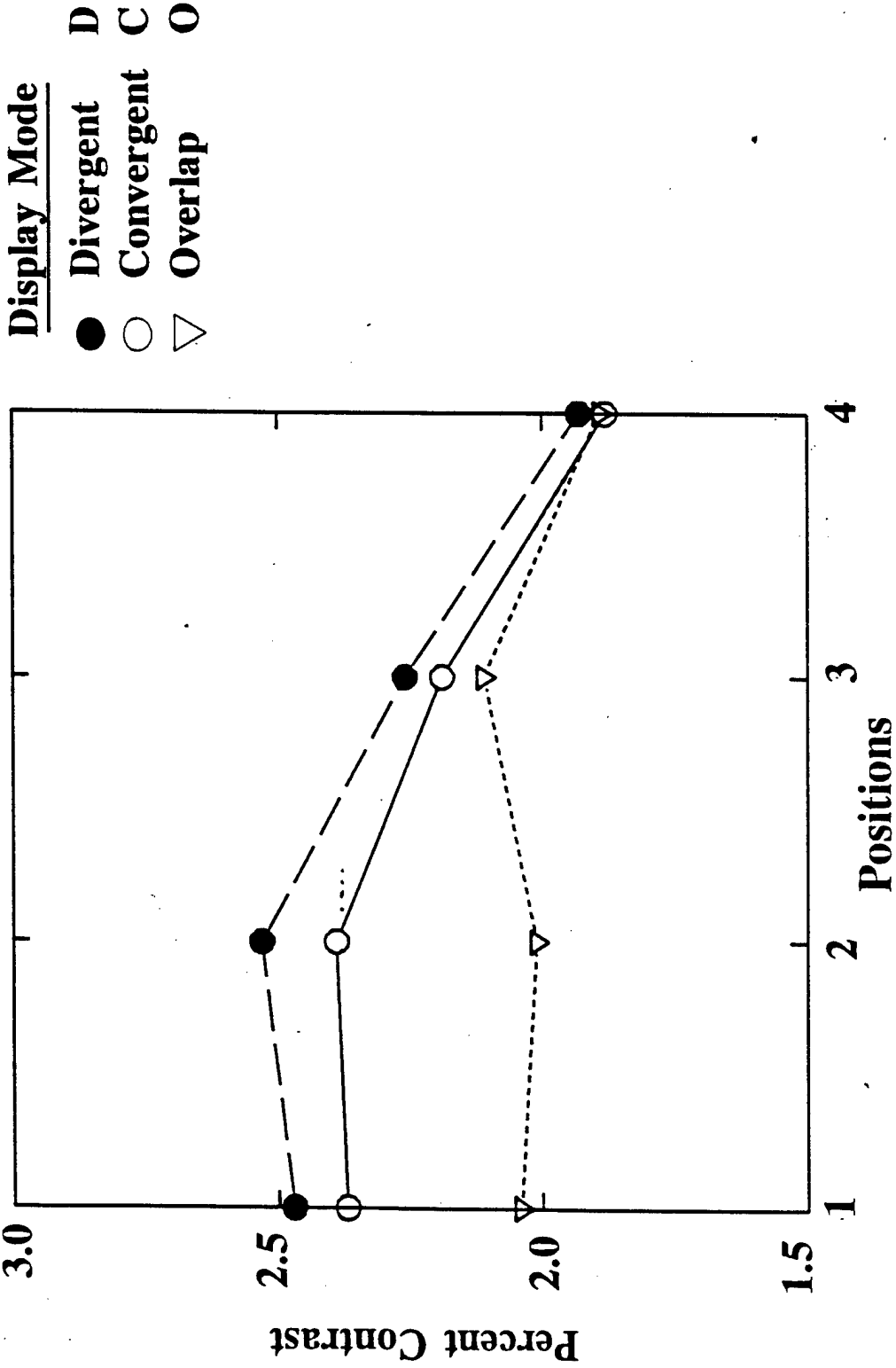
- Divergent D
- Convergent C
- ▽ Overlap O

t-test	p <		
C v D	NS	.01	NS
O v C	.0025	*	.0025
O v D	*	*	.01

\* = p < .0001

NS	NS	NS	NS
.0025	.0025	.0025	NS
*	.01	.01	NS

# 4.24 cpd 3.75 Hz



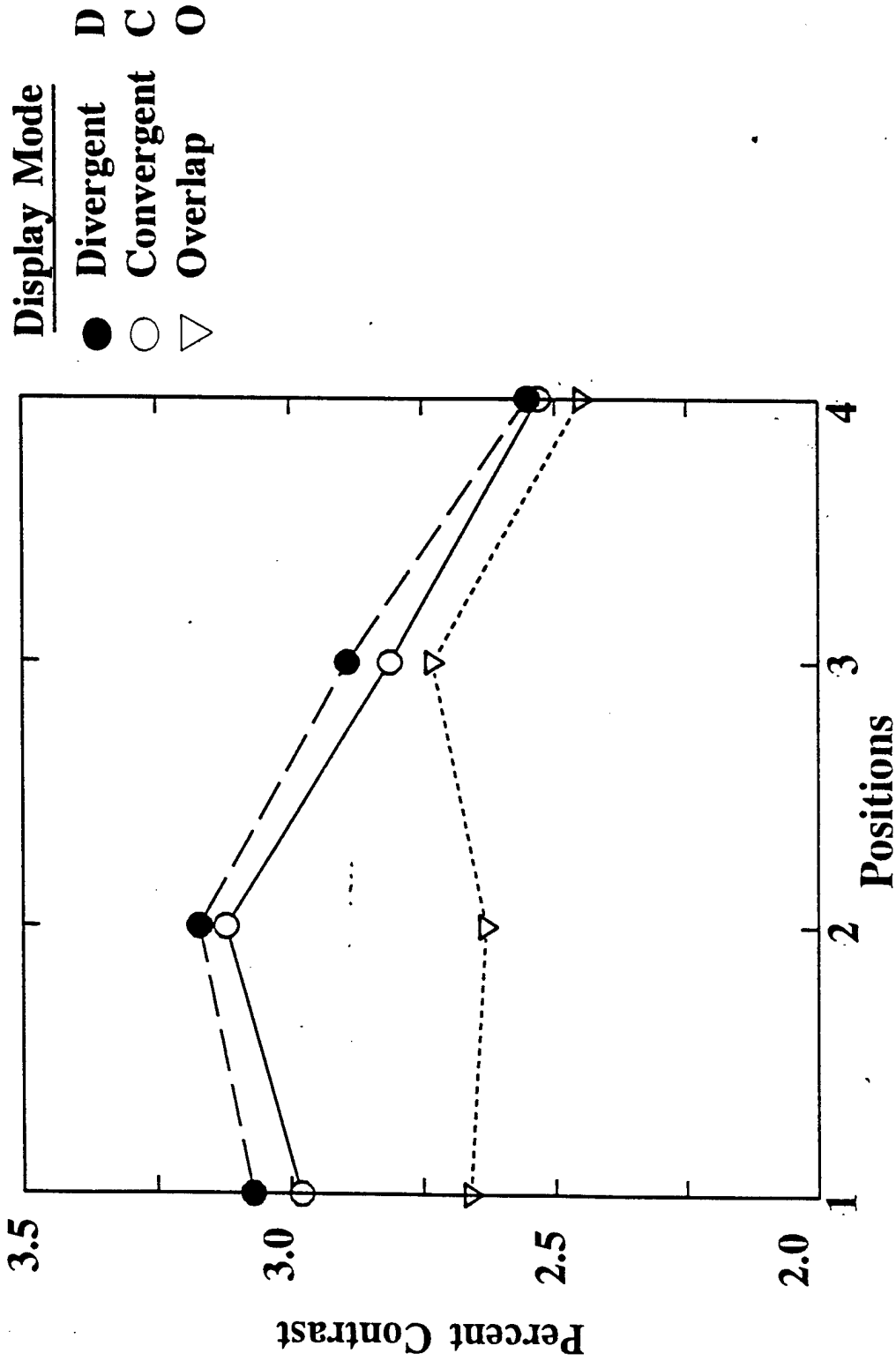
t-test

C v D	NS	NS	.05	NS
O v C	.0005	*	NS	NS
O v D	*	*	.0025	NS

p <

\* = p < .0001

# 4.24 cpd 7.5 Hz



## Display Mode

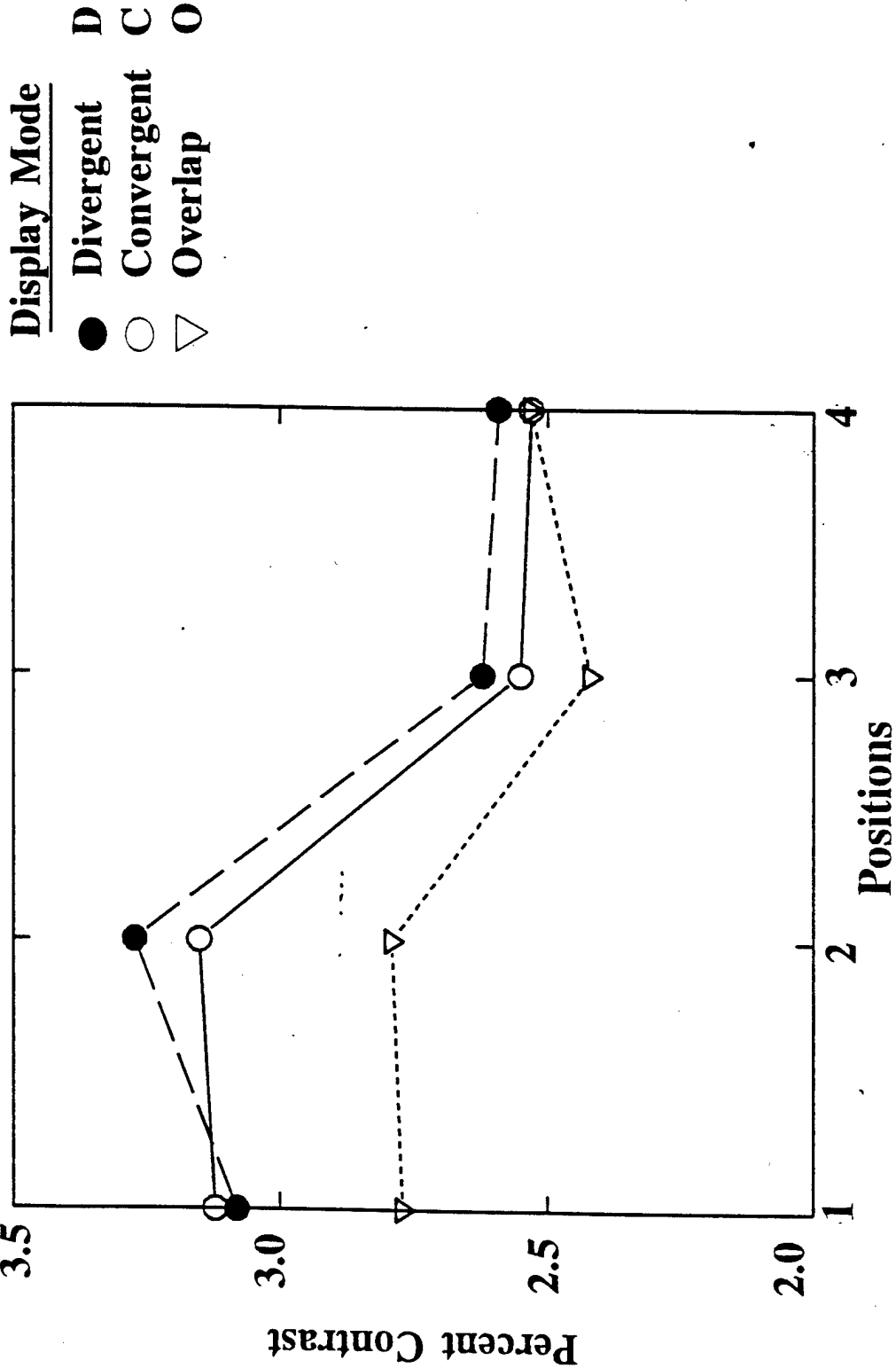
- Divergent D
- Convergent C
- ▽ Overlap O

## t-test

t-test	p <		
C v D	NS	NS	NS
O v C	*	NS	.01
O v D	*	.01	.001

\* = p < .0001

# 2.12 cpd 0 Hz



t-test

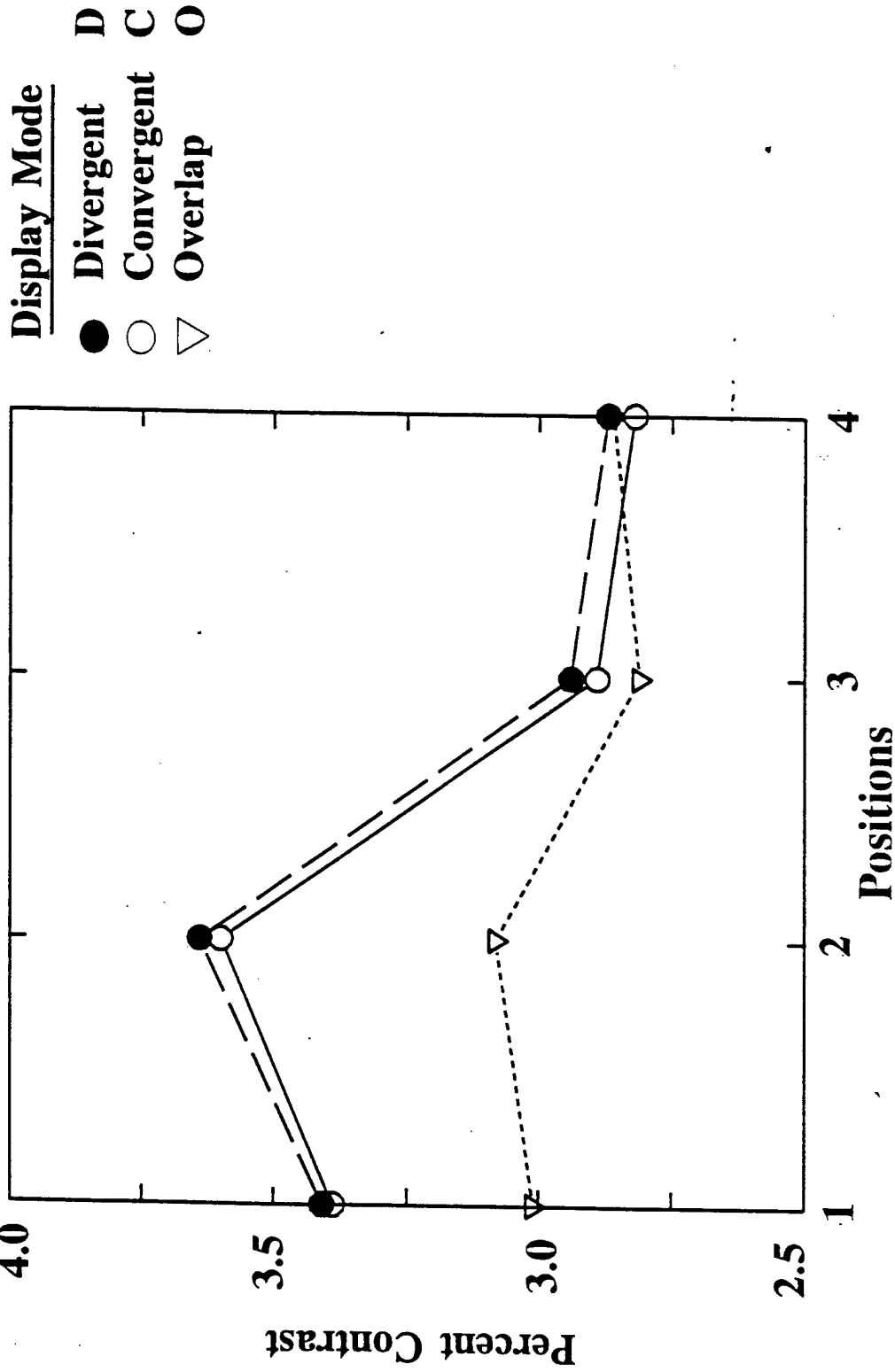
C v D  
O v C  
O v D

p<

NS	NS	.05	NS
.00025	*	.0005	NS
*	*	.00025	NS

\* = p<.0001

# 2.12 cpd 15 Hz



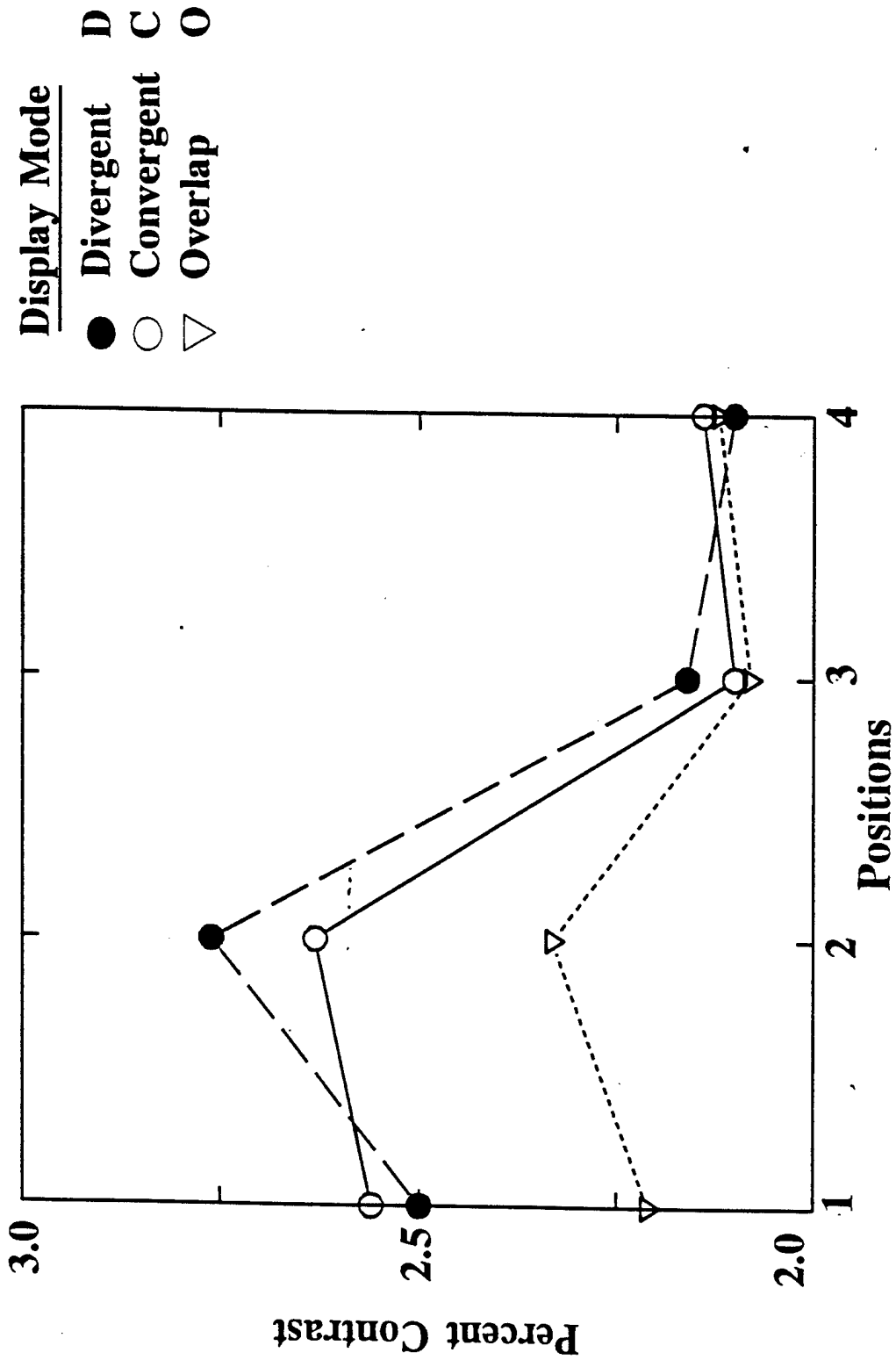
**t-test**

C v D	NS	NS	NS	NS
O v C	*	*	.025	NS
O v D	*	*	.005	NS

p <

\* = p < .0001

2.12 cpd      3.75 Hz



t-test

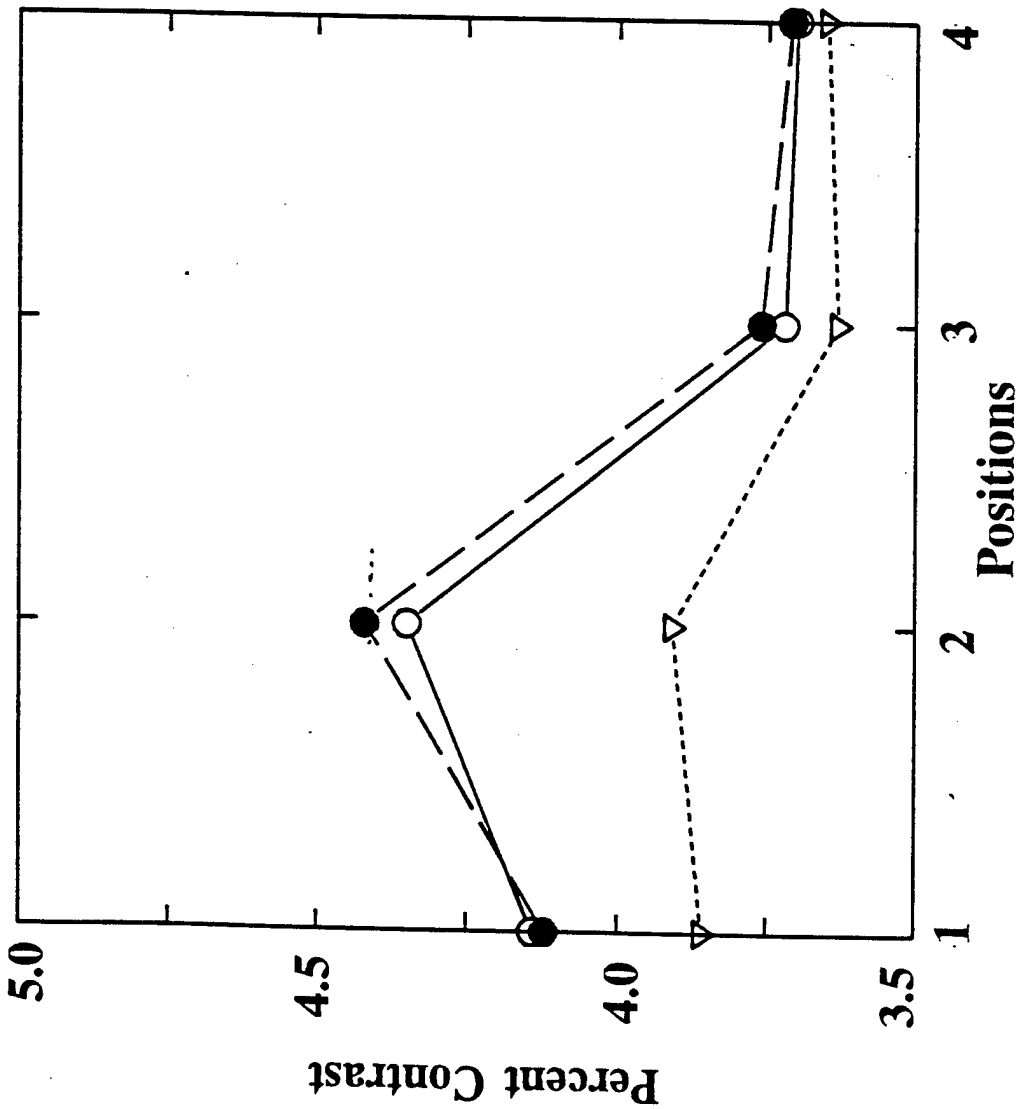
C v D	NS	NS	NS	NS
O v C	*	*	NS	NS
O v D	*	*	.025	NS

p <

\* = p < .0001

# 2.12 cpd 7.5 Hz

Display Mode  
**●** Divergent **D**  
**○** Convergent **C**  
**▽** Overlap **O**



t-test

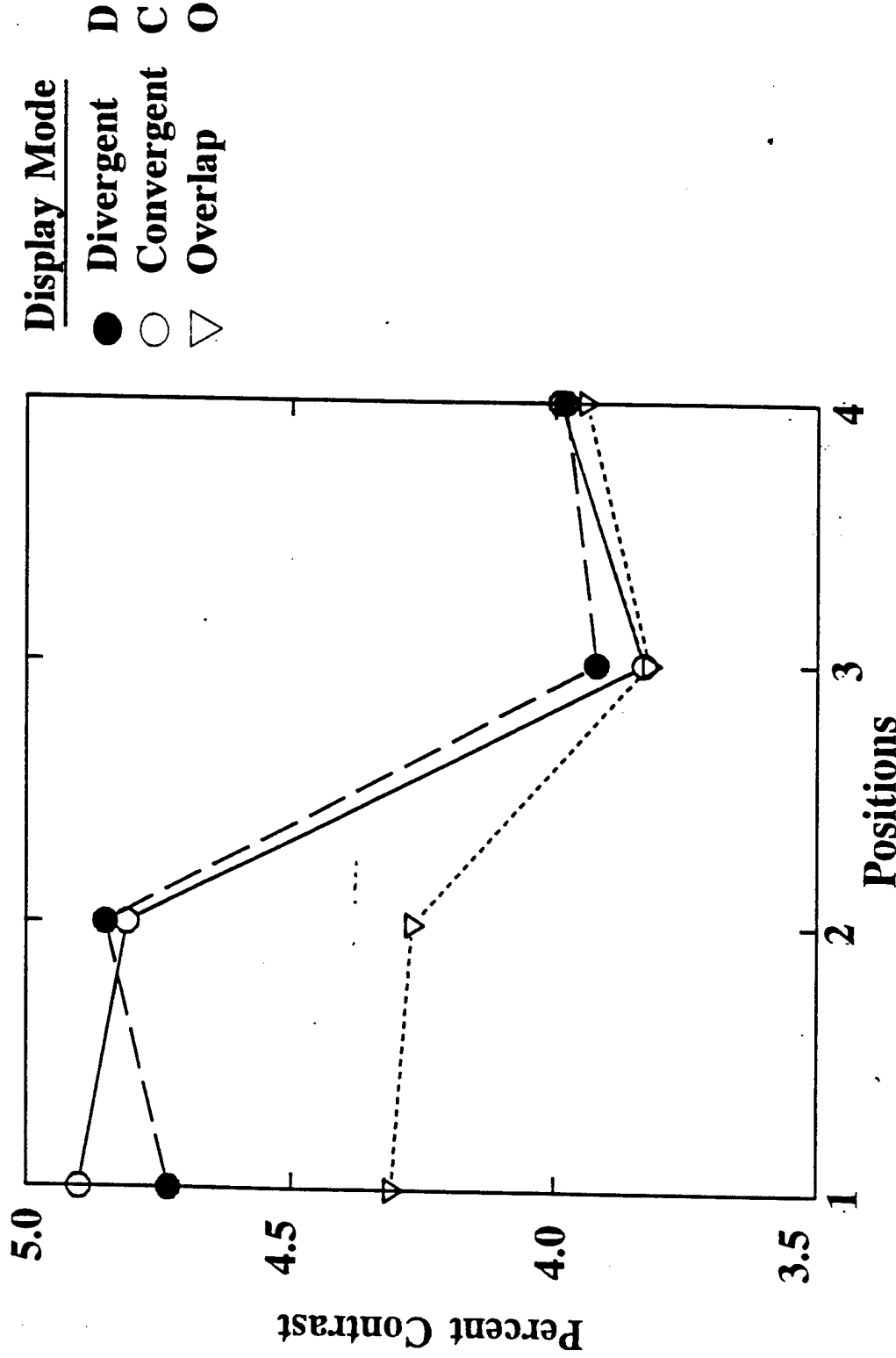
C v D  
 O v C  
 O v D

p <

NS	NS	NS	NS
.00025	*	.01	NS
.0005	*	.0005	.05

\* = p < .0001

# 1.06 cpd 0 Hz



## Display Mode

- Divergent D
- Convergent C
- ▽ Overlap O

## t-test

- C v D
- O v C
- O v D

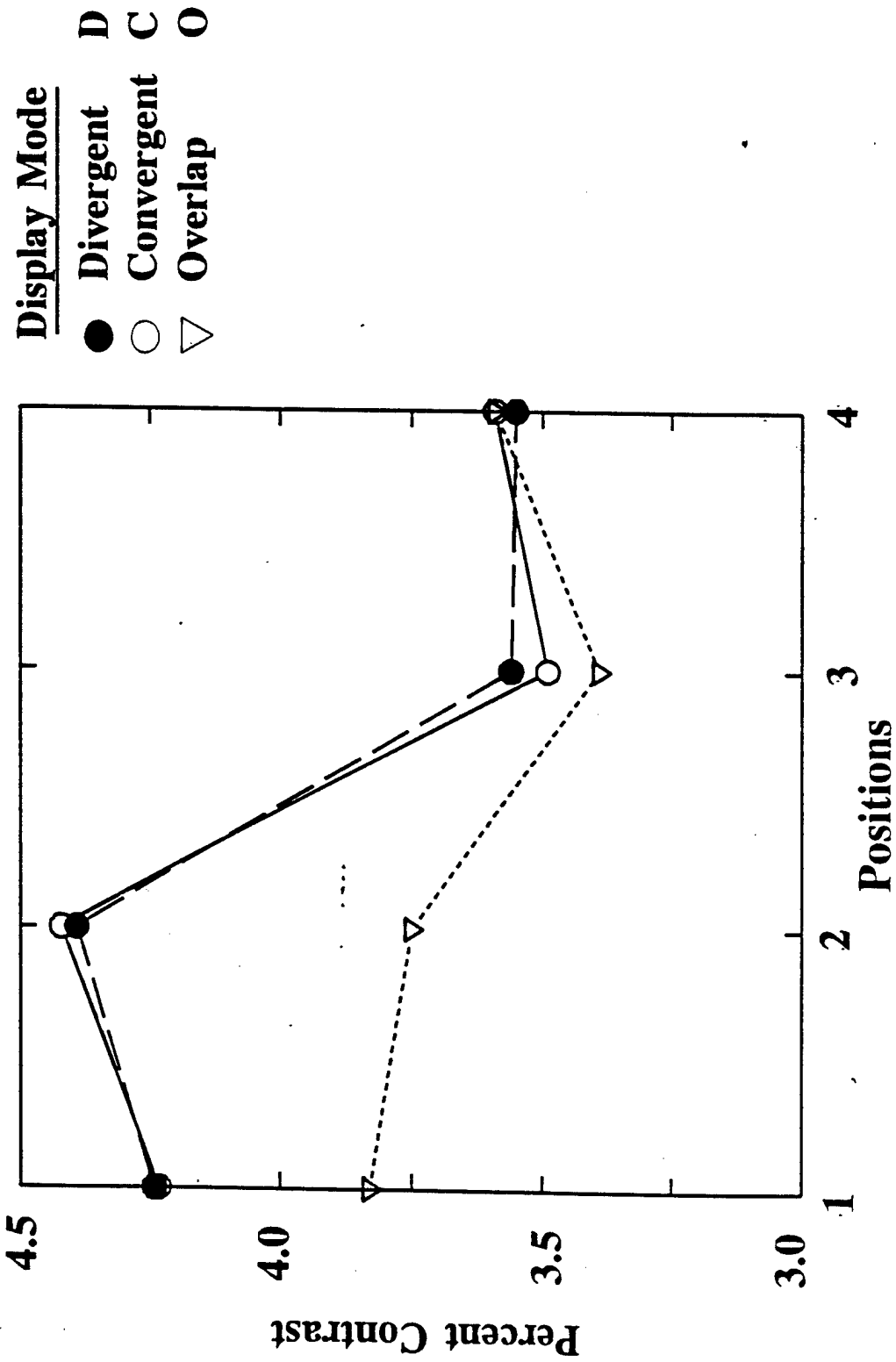
NS	NS	NS	NS
*	*	NS	NS
.0005	*	NS	NS

\* = p < .0001

p <

Positions

# 1.06 cpd 3.75 Hz



**Display Mode**  
**● Divergent**  
**○ Convergent**  
**▽ Overlap**

t-test

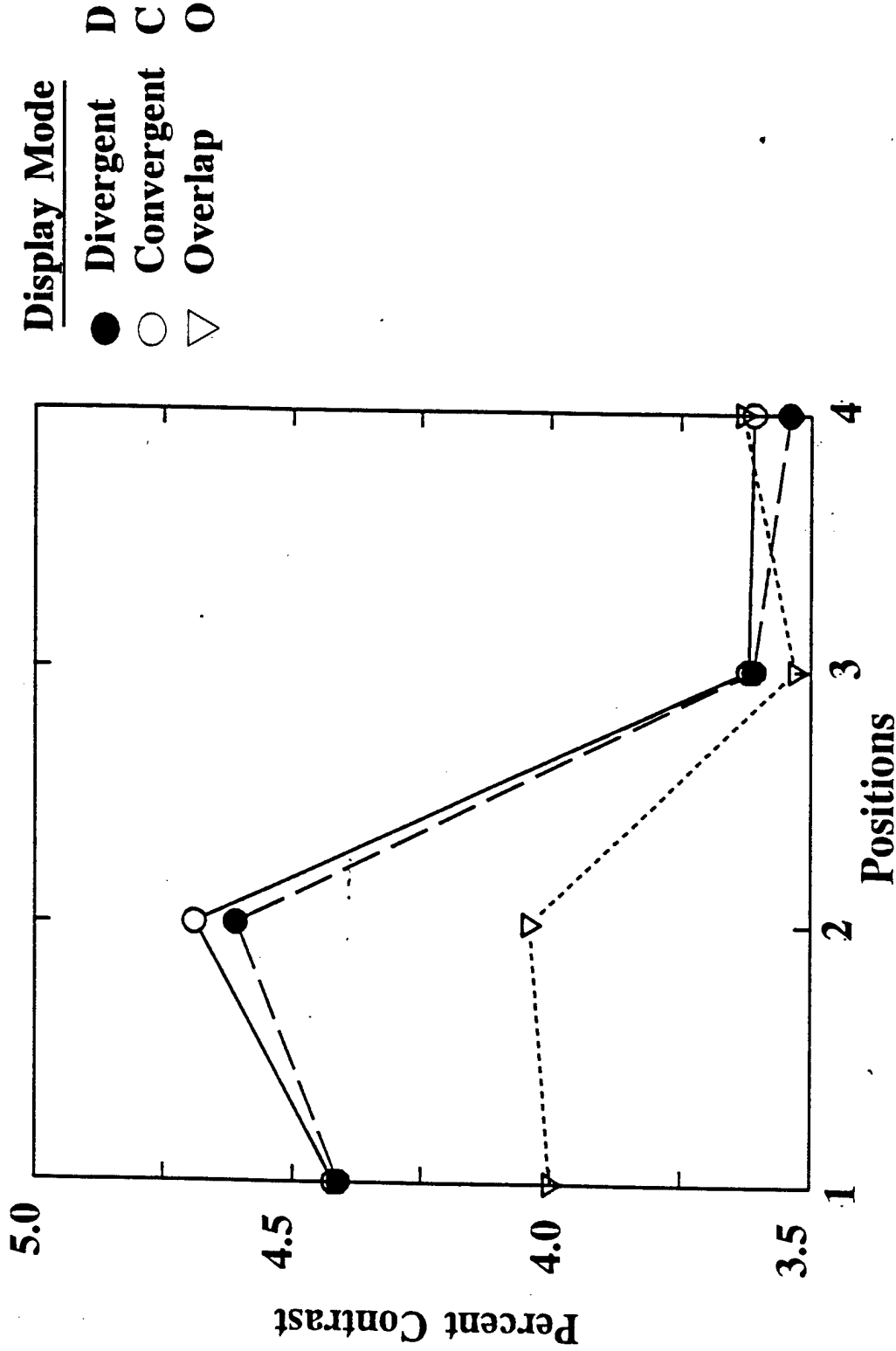
C v D  
 O v C  
 O v D

NS	NS	NS	NS
*	*	NS	NS
*	*	.025	NS

p <

\* = p < .0001

1.06 cpd 7.5 Hz



Display Mode  
**D** Divergent  
**C** Convergent  
**O** Overlap

t-test

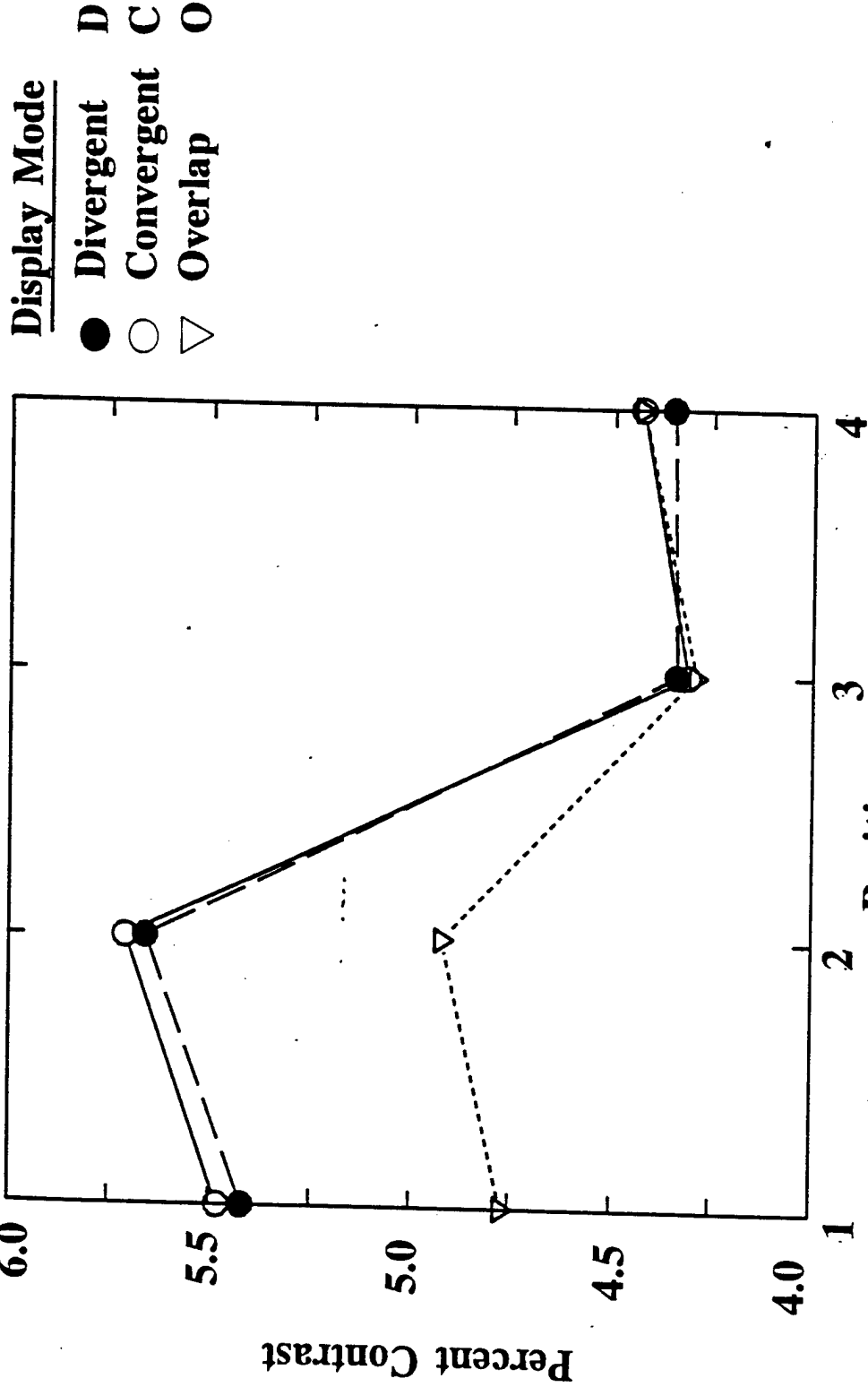
C v D	NS	NS	NS	NS
O v C	.0005	*	NS	NS
O v D	.0005	*	NS	NS

\* = p < .0001

p <

Positions

# 1.06 cpd 15 Hz



## Display Mode

- Divergent D
- Convergent C
- ▽ Overlap O

## t-test

C v D	NS	NS	NS	NS
O v C	.0001	*	NS	NS
O v D	*	*	NS	NS

\* = p < .0001

## Conclusions

As expected, for positions 1 and 2, contrast thresholds were higher for the monocular probes in the Convergent and the Divergent display modes than for the binocular probes in the complete Overlap display mode.

For high spatial frequency probes, these contrast thresholds were higher in the Divergent than in the Convergent mode. Thresholds were higher, and the divergent convergent difference was greater, for monocular positions adjacent to the monocular/binocular border.

In positions 3, thresholds were, in some cases, higher in the Convergent and Divergent modes than in the Overlap mode showing the influence of the adjacent monocular/binocular border on binocular probe stimuli.

A number of factors are implicated, including binocular rivalry and suppression, color brightness spreading, and edge effects (see references), which we will discuss elsewhere. In brief, we ecologically model the display modes (see Barrand, 1979; Gibson, 1979; Melzer and Moffitt, 1989, 1991) in terms of what has come to be known as DaVinci stereopsis (Nakayama and Shimojo, 1990) and analyze the visual system's responses to different ecological interpretations of the visual world (see Shimojo and Nakayama, 1989).

## REFERENCES

- Barrand, A. G. (1979). An Ecological Approach to Binocular Perception: The Neglected Facts of Occlusion. Doctoral Dissertation, Cornell University.
- Blakemore, C. (1969). Binocular depth discrimination and the nasotemporal division. Journal of Physiology, 205, 471-497.
- Curcio, C. A. and Allen, K. A. (1990). Topography of ganglion cells in human retina. The Journal of Comparative Neurology, 300, 5-25.
- Edgar, G.K., Carr, K.T., Williams, M. and Clark, A.L. (1991). The effect upon visual performance of varying binocular overlap. AGARD Proceedings.
- Fox, R. and Check, R. (1968). Detection of motion during binocular rivalry suppression. Journal of Experimental Psychology, 78(3), 388-395.
- Gibson, J.J. (1979). The Ecological Approach to Visual Perception. Houghton-Mifflin: Boston, MA.
- Gillam, B. and Borsting, E. (1988). The role of monocular regions in stereoscopic displays. Perception, 17, 603-608.
- Kaufman, L. (1963). On the spread of suppression and binocular rivalry. Vision Research, 3, 401-415.
- Klymenko, V., Verona, R. W., Martin, J. S, Beasley, H.H. and McLean W. E. [in preparation]. Factors affecting fragmentation of partial binocular overlap displays.
- Kruk, R. and Longridge, T. M. (1984). Binocular overlap in a fiber optic helmet mounted display. The Image 3 Conference Proceedings, 363, 363-377. Air Force Human Resources Lab.
- Landau, F. (1990). The effect on visual recognition performance of misregistration and overlap for a binocular helmet mounted display. SPIE Proceedings, Vol. 1456, Helmet-Mounted Displays II, San Jose, CA: SPIE-The International Society for Optical Engineering.
- Matelli, F. (1974). The perception of transparency. Scientific American, 230, 91-98.
- Melzer, J. E. and Moffitt, K. (1991). An ecological approach to partial binocular-overlap. SPIE Proceedings, Vol. 1456, Large Screen Projection, Avionic, and Helmet-Mounted Displays, San Jose, CA: SPIE-The International Society for Optical Engineering.
- Melzer, J. E. and Moffitt, K. (1989). Partial binocular overlap in helmet-mounted displays. SPIE Proceedings, Vol. 1117, Display System Optics II, San Jose, CA: SPIE-The International Society for Optical Engineering.
- Nakayama, K. and Shimojo, S. (1990). Da Vinci stereopsis: Depth and subjective occluding contours from unpaired image points. Vision Research, 30, 1811-1825.
- Nakayama K, Shimojo, S. and Ramachandran, V. S. (1990). Transparency: relation to depth, subjective contours, luminance, and neon color spreading. Perception, 19, 497-513.
- Nakayama K, Shimojo, S. and Silverman (1989). Stereoscopic depth: Its relation to image segmentation, grouping, and the recognition of occluded objects. Perception, 18, 55-68.
- Ono, H., Shimono, K., and Shibuta, K. (1992). Occlusion as a depth cue in the Wheatstone-Panum limiting case. Perception & Psychophysics, 51, 3-13.
- Shimojo, S. and Nakayama, K. (1990). Real world occlusion constraints and binocular rivalry. Vision Research, 30, 69-80.
- Wells, M. J., Venturino, M. and Osgood, R. K. (1989). The effect of field-of-view on performance at a simple simulated air-to-air mission. SPIE Proceedings, Vol. 1116, Helmet-Mounted Displays, San Jose, CA: SPIE-The International Society for Optical Engineering.
- Yang, Y., Rose, D. and Blake, R. (1992). On the variety of percepts associated with dichoptic viewing of dissimilar monocular stimuli. Perception, 21, 47-62.