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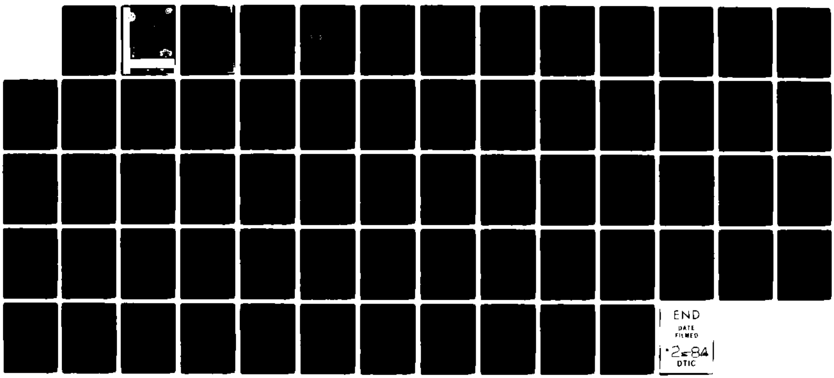

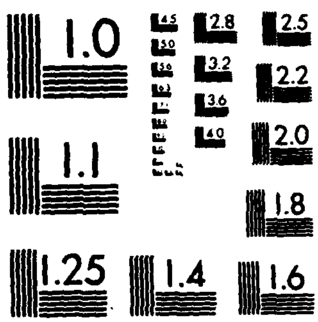

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A helmet-mounted display being procured for the Navy's Visual Technology Research Simulator will display two computer-generated images of the scene to be viewed by the trainee pilot, the first inset inside the second, following eye direction and showing a higher level of detail version of the scene than the second, low resolution, low detail, wide angle image. Experiments in which spatially and temporally varying sinusoidal bar

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patterns are displayed on an Optronix Vision Tester suggest that a contrast blend region around the inset will be effective in suppressing the "popping" of objects and image detail in and out of view as they move across the inset boundary. These experiments also suggest a restriction upon scene modeling which may be helpful in mitigating popping--namely that the largest size of detail associated with a form (the external border between form plus shadow, and background) be changed least. (Internal contours are added or subtracted first.) In further experimentation, locus of attention is shown to have little effect upon perceived popping, but adaptation may have large effects. Other potentially problematic perceptual phenomena resulting from the throughput delay of the planned display system, and experimental manipulations and a device for investigating these potential effects are identified.

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SUMMARY

Studies have revealed that "popping" can be expected to occur in helmet-mounted, area-of-interest, computer-generated imagery displays anticipated for use in the Visual Technology Research Simulator (VTRS), and elsewhere. "Popping" is the compelling phenomenal appearance of new scene content as it passes from the low levels of detail available in the periphery, or background, to the high levels of detail within the area of interest. Ramping contrast over a blend region between area of interest and background, and restricting the size of scene content that is present in the higher but not lower level of detail models were the chief methods studied to alleviate the problem. Four groups of experiments were performed.

The first group of studies dealt with preliminary investigations of contrast sensitivity as a function of: 1) retinal eccentricity; 2) rate of pattern motion; and 3) temporal modulation (counterphasing). The results showed that the data (obtained with an Optronix Vision Tester) are valid; findings to be expected from the research literature were replicated. Also, the results suggested that the popping problem may be addressed by varying the temporal contrast modulation of the test patterns.

The second group of experiments was based on the idea of varying the temporal contrast modulation; detection threshold for "popping" and subjective impressions of popping were measured as a function of spatial frequency and temporal waveform.

In our judgment this second set of studies produced the most important implications for the design of area-of-interest displays. The results of these experiments suggest that popping will be more pronounced for lower spatial frequencies, and that popping depends upon the slope of the temporal onset and offset of the high level of detail material. From these findings we conclude that a contrast blend region between the area-of-interest display and the background at the proposed retinal eccentricity will suppress popping. Also, models of objects at different levels of detail ought not to differ in external contours (including the casting of shadows), but may differ in their internal contours.

A third set of experiments explored the extent to which popping might be attenuated by adaptation to particular temporal and spatial frequencies.

In the fourth set of experiments, an attempt was made to discover whether popping is attenuated when the observer must attend to a different part of the visual field.

A five-degree wide blend region between levels of detail surrounding the twenty degree area-of-interest display, which ramps contrast of high detail will be effective in suppressing popping. These experiments also suggest a restriction upon scene modeling which may be helpful in mitigating popping--namely, that the largest size of detail associated with a form be changed least. Stated differently, internal contours should be added or subtracted first.

Other factors (adaptation, focus of attention) were investigated in a series of screening studies. The effects of these variables, which are relevant to estimates of the degree of popping that may be expected in eye-coupled area-of-interest displays, are summarized. Suggestions for future research are offered.

SECTION I

GENERAL INTRODUCTION

The designers of a new helmet-mounted, eye-coupled computer-generated image display system for VTRS have been concerned that this system may occasion unacceptable "popping" of objects into view as the scene layout passes from low to high level of detail areas of the display. In this system, computer-generated imagery is displayed through a target projector with a narrow field and a background projector with a wider field. The target projector and background projector are slaved to the observer's eye, so that wherever the eye is fixated, a high level of detail will be seen. The background projector only displays a low level of detail. This concern was exacerbated by a film which was made to simulate the new display system and which evidenced unacceptable popping with discontinuous changes in level of detail (Breglia, 1981, technical memorandum).

The purpose of the current experiments was to investigate the popping phenomena in order to understand the visual mechanisms involved and to recommend methods of stimulus presentation which minimize, or remove, the effect (see Allen, 1982, technical memorandum). Methods for controlling popping which could be considered within the context of the developing eye-coupled display system include: 1) a contrast blend region between a foveally coupled area-of-interest field presented at a high level of detail, and a background field of view presented at a much lower level of detail; 2) data base design constraints on the way that scenes are modeled in different levels of detail in the data base of the computer image generator. [It was recognized that whether for the AOI, background or blend region displays, the latter possibility would have to be in the form of rules or heuristics that could easily be applied by scene modelers and which would state implicitly the stimulus attributes that must be shared by objects modeled at different levels of detail, if they are to be perceived as equivalent (i.e., would not appear to "pop" into view).]

SECTION II

EXPERIMENT 1

PRELIMINARY REPLICATIONS OF PREVIOUSLY REPORTED CONTRAST SENSITIVITY FINDINGS, WITH SEVERAL EXTENSIONS RELEVANT TO THE POPPING PROBLEM

INTRODUCTION

The contrast sensitivity to static, moving and counterphasing sinewave gratings at several retinal eccentricities was measured in two preliminary subjects. Contrast sensitivity is defined as the reciprocal of threshold contrast (so that sensitivity increases as threshold decreases). Threshold is the minimum contrast required to see a pattern. Contrast for a periodic pattern is:

$$\text{contrast} = \frac{L_{Max} - L_{Min}}{L_{Max} + L_{Min}},$$

where L_{Max} is maximum luminance and L_{Min} is minimum luminance. This initial work was an attempt at replicating findings to be expected from the research literature, in order to validate our methodology, and also to extend our understanding to the particular stimulus conditions occasioned by the new eye-coupled display system. These studies allowed stimulus variables and response measures to be discovered which could be used to directly address the popping problem.

METHOD

STIMULI. All stimuli were presented on the viewing screen of the Optronic Vision Tester, which is described elsewhere in detail (cf., Optronix Operating Manual 1981). The average luminance of the screen was 100 cds/sq. m, and the peak contrast of the patterns was 0.5 (set using the Optronix Internal Photomoter). Six spatial frequencies of vertically oriented gratings varying sinusoidally in contrast were used in these investigations. Spatial frequencies were 0.5, 1.0, 3.0, 6.0, 11.4, and 22.8 cycles per degree. Static, moving and counterphased gratings were tested. Stimuli were viewed from a distance of 3 meters either foveally, or 10 or 15 degrees parafoveally. The proper parafoveal eccentricity (0, 10, 15) was maintained by the use of a fixation point.

APPARATUS. Stimuli were presented on the viewing screen of an Optronix 200 Vision Tester which incorporates a microprocessor to control a modified video monitor. This device permits automated determination of threshold contrast sensitivity for spatial waveforms (gratings) having various spatial frequencies temporally modulated with various temporal waveforms (static, moving, sinusoidally counterphasing, and other user-defined options are available). Preprogrammed procedures and psychophysical measures were used in the conduct of all experiments. Wherever possible, viewing conditions and values of stimulus variables were those recommended by the manufacturer of the device.

The viewing screen of the Optronix 200 Vision Tester is 22cm wide, 29.2cm in height, and contains 392 raster lines.

Calibration of brightness and contrast was accomplished using a semiautomatic procedure and the photometer provided with the Optronix. The values provided were checked by an independent photometer manufactured by SEI. Calibration occurred at the beginning of each daily session and was also checked several times during the session.

PROCEDURE. Two subjects (KB and JA) participated in the experiment. JA's vision is corrected with glasses and KB is farsighted (uncorrected). Contrast sensitivity of the subjects for static and moving gratings was measured using the von Bekesy psychophysical method. A single experimental trial consisting of eight measurements was conducted for each subject for each combination of spatial frequency, temporal frequency and retinal eccentricity. Each trial began with a preview of the waveform of interest at peak contrast (0.5) for two seconds. The contrast then went to zero and was then slowly increased at the rate of zero to peak contrast in 30 seconds. Subjects pressed a response key as soon as they could detect the pattern of interest, and held the key down for so long as they could still detect the pattern. Whenever the response key was held down, the contrast was decreased (at a similar rate). The subject released the key as soon as he could no longer detect the pattern. Thus each depression and release of the response key reversed the direction of the change in contrast. The stimulus contrast at the point of reversal was used as a measure of threshold. Eight such measures (reversals) were collected and averaged for each trial.

The experiment was conducted in blocks; each block including the six spatial frequencies. Thus, 12 blocks were required to complete the combinations of four rates of motion

(0, 1, 3, and 5 degrees per second) and three positions of fixation (0, 10, and 15 degrees of retinal eccentricity). (The proposed contrast blend region would lie between 10 and 15 degrees parafoveally.)

In a second part of the experiment, one subject (KB) observed counterphasing gratings, wherein the contrast was modulated sinusoidally. Four rates of temporal modulation (1, 5, 10, and 15 cycles per degree) and three retinal eccentricity locations were included. Method of adjustment was used in this part of the investigation. In the method of adjustment, the subject adjusts a potentiometer on the response box to adjust the peak contrast of the test pattern so that it is just barely detectable. This method was used because, since the counterphase rates were quite slow, the von Bekesy tracking procedure was inappropriate.

RESULTS

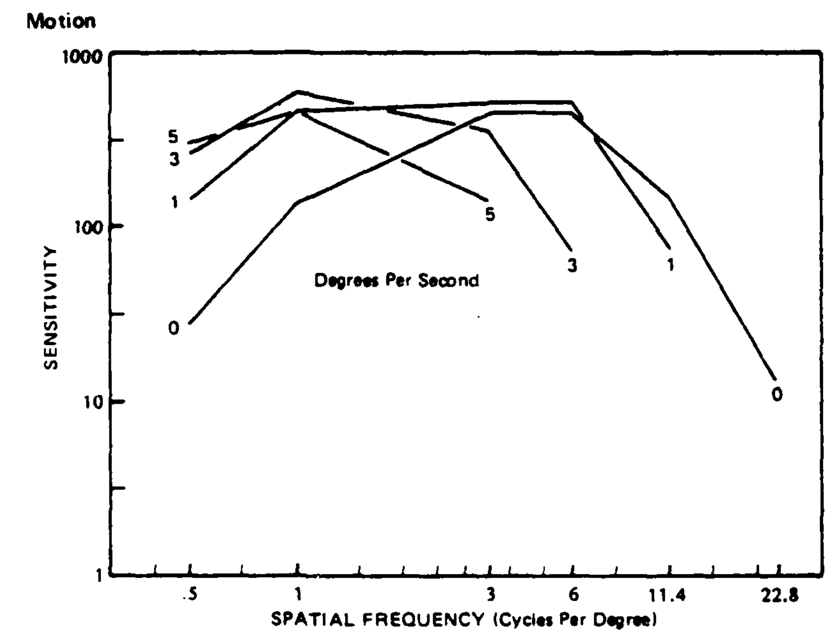
The major portion of the results for this experiment are shown in Appendix A. In Figures A-5, A-6 and A-7, the data are plotted in various ways. In Tables A-2 and A-3 the raw data are listed. Except for graphs depicting subjective ratings, for all graphs presented in this report, the ordinate is contrast sensitivity; the reciprocal of threshold contrast. However, all raw data and analyses are in terms of logarithmic threshold contrast. This is because graphs are easier to read in terms of sensitivity, but log threshold contrast is more appropriate for statistical analysis. The relation between the graphs and tables is given by the equation:

$$\text{sensitivity} = \frac{1}{10}^{\text{(log contrast threshold)}}.$$

In Figure A-5 of Apendix A, the data for subjects JA and KB are plotted separately. For each subject there are four graphs; one for each of three motion rates (1, 3, and 5 degrees/second) and static. In each of the graphs, there are three functions; one for each retinal location (0, 10, and 15 degrees). Figure A-5 can be used to compare the sensitivity function of spatial frequency for various retinal eccentricities. Figure A-6 of the Appendix actually plots the same data in a somewhat different fashion. Again, there are separate functions for subjects JA and KB; however, in Figure A-6 there are three graphs for each subject; one for each retinal eccentricity. There are four functions drawn on each graph, one for each rate of motion. Thus, Figure A-6 can be used to compare contrast sensitivity to various spatial frequencies as the velocity of motion is changed.

From Figure A-5 it is clear that increasing retinal eccentricity produces a linear decline in sensitivity across spatial frequency. This is true for all rates of motion. From Figure A-6 it is clear that with increasing rates of motion, sensitivity to low spatial frequencies improves, while sensitivity to high spatial frequencies declines. This effect can be seen at all retinal eccentricities and replicates what are now classic experiments (Breitmeyer & Ganz, 1976; Kulikowski & Tolhurst, 1973; Tolhurst, 1973). These graphs may reflect the activity of what have been proposed to be two information channels in, or components of, the human visual system (Breitmeyer & Ganz 1977; Regan, 1982). One component, the "sustained" system, is attuned to high spatial frequency and low temporal frequency. Thus, it registers high detail which does not move. Its other features are that it has a long response latency, low conduction velocity, and is mapped to the fovea. The other component, the "transient" system, is attuned to low spatial frequency and high temporal frequency. Thus, things that move tend to be registered as blobs (no high frequencies). Other features of this system include short response latency, high conduction velocity, and mapping to the peripheral visual field. Several researchers (Breitmeyer & Ganz, 1976; Posner, 1980) feel that the transient visual system directs visual attention and eye movement; it serves as an "early warning system" which reports where interesting things (things which move) are located in the visual field.

Counterphase contrast sensitivity functions for subject KB are shown in Figure A-7 of Appendix A. (A counterphase grating substitutes white bars for black bars, and black bars for white bars, so that halfway through the temporal cycle the screen is blank.) There is also evidence in the literature to support this contention (Breitmeyer and Ganz, 1976; Kulikowski and Tolhurst, 1973; Tolhurst, 1973; Pantle, 1972). The left side of the page shows four graphs; one each for the four counterphase rates (1, 5, 10, 25 cycles/second). The right side of the page shows three graphs; one for each retinal position of the test grating. Note the similarity between the graphs on the left side of Figure A-7 and the graphs on Figure A-5. Also, note the similarity between the graphs on the right side of Figure A-7 and those of Figure A-6. It appears from such comparisons that increasing the rate of motion has the same effect as increasing the counterphase modulation rate. (This is not too surprising, considering that a counterphase grating can be produced by superimposing two gratings which are moving in opposite directions. Figure 1 compares KB's contrast sensitivity for various rates of motion with his contrast sensitivity for various rates of counterphasing. In each case, increasing temporal modulation is accompanied by increases in low spatial frequency sensitivity and decreases in high spatial frequency sensitivity.



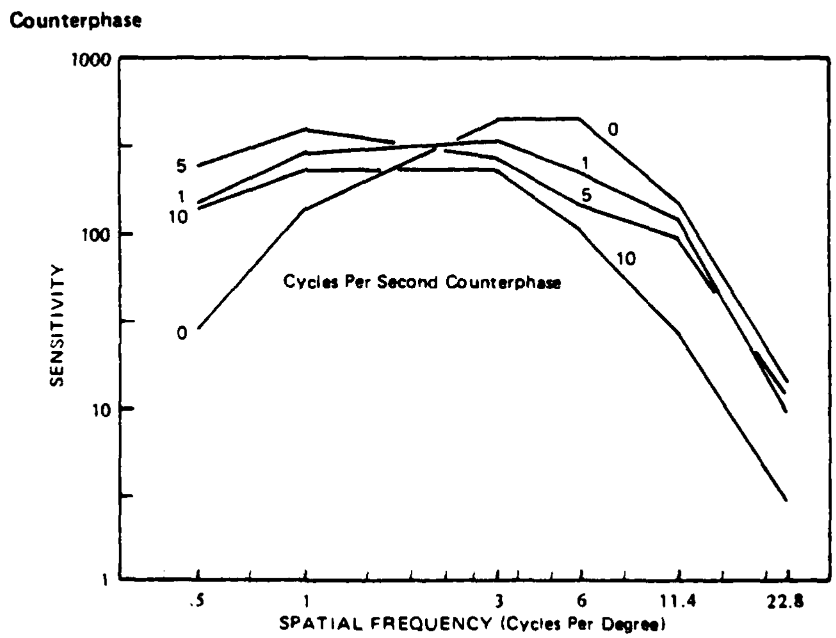


Figure 1. Comparing Contrast Sensitivity to Moving and Counterphasing Gratings (Foveal)

DISCUSSION

Our replication of findings from the literature provides support that the Optronix Vision Tester provides us with veridical measurements of contrast sensitivity. Furthermore, the results suggest that more eccentric retinal locations are less sensitive to all spatial frequencies (all sizes) about equally. Finally, for patterns that either move or change contrast, larger patterns (those with lower spatial frequency components) will be easier to detect than smaller patterns. Comparison of motion and counterphasing (see Figure 1) suggests a method that can be used to further investigate the popping phenomena.

As material moves across the blend region, it also changes contrast physically as it changes position, and it appears to pop into view (Spooner, technical memoranda). However, the movement of material across the blend region may not always reflect movement of, or in, the scene; stationary objects may enter the blend region when the observer moves his eyes (e.g., pursuit eye movement). Since popping occurs both by a change in position and by a change in contrast, the question is whether both changes are registered in the visual system by the same mechanisms. This situation is very important for the current investigations, because by using the Optronix, we cannot change the contrast of a grating that is moving. However, we can alter the contrast of a stationary grating as a function of time. Our first experiment suggested that the effects of motion and of counterphase contrast modulation on contrast sensitivity are similar. Since contrast and position for material crossing the blend region vary together, and since these two variables (contrast change and position change) affect the same mechanisms in the visual system, it is likely that results obtained for patterns that vary in contrast only can be generalized to patterns that change in contrast and position. There is also evidence in the literature to support this contention (Breitmeyer and Ganz, 1976; Kulikowski and Tolhurst, 1973; Tolhurst, 1973; Pantle, 1973).

SECTION III

EXPERIMENT 2

POPPING THRESHOLD AND RATINGS OF POPPING AS A FUNCTION OF COUNTERPHASE WAVEFORM AND FREQUENCY

INTRODUCTION

In Experiment 2, we attempted to address the problem of popping directly, by testing sensitivity to gratings of different sizes and rates of change in contrast. The rationale and methodology for this investigation resulted from the earlier study. However, in the current experiments, we declined to use the sinusoidal counterphase waveforms of the earlier experiment, because change in contrast does not occur at a constant rate for these stimuli. For sinusoidal contrast modulation, there is an acceleration in contrast change as the contrast approaches zero, but there is a deceleration in the contrast change as the contrast departs from zero. One report in the research literature (Breitmeyer & Julesz, 1975) contends that the slope of the onset and offset of a stimulus determines the transient visual system response to that stimulus. Since the transient system is implicated in perception of popping, it is critical to obtain good control over this variable in the current experiments. Therefore, we selected two other temporal waveforms: triangular and rectangular. The triangular waveform was not present as a preprogrammed feature in the Optronix device, but could be included as a user-defined function. A very elegant procedure for encoding the triangle function into the Optronix was developed for us by Becker (technical memorandum, 1982). These two waveforms permit the importance of rate-of-contrast change and of frequency-of-contrast change to be determined. In the triangular waveform, onset and offset slope change as a function of frequency; in the rectangular waveform, since the slopes of onset and offset are infinite, they are unchanged regardless of the modulation frequency.

In the course of conducting the first study, we began to question whether a measurement of simple contrast sensitivity could actually capture the nature or quality of the popping phenomena. Perceptually, an object, or new detail, popping into or out of view is very different from a steady state object. In attempting to control popping, sensitivity to steady state or ordinary movement is not really the issue. (Of course, it would be important if such properties could not be detected.) It is the sudden, anomalous, noticeable changes (pops or jumps) that are not ordinarily present in a scene but which may accompany new area-of-interest displays that are of concern. Thus, the appropriate response measure for the current experiments ought to reflect sensitivity to change, rather than simple sensitivity to stationary patterns. To study this, we invented two response measures: "popping threshold" and "rating of popping." To obtain the first measure, subjects adjusted the peak contrast of the gratings to the point at which an eye-catching temporal discontinuity, could just be detected. This point was operationally defined as the popping threshold. To obtain the other measure, subjects rated the noticeability of the gratings counterphased to peak contrast. This latter response was included for two reasons: 1) Visual systems sometimes exhibit different characteristics when threshold versus suprathreshold responses are measured. 2) Rating scales are often employed successfully in quantifying complex perceptual judgments (Wiker, Kennedy, Pepper & McCauley, 1979). The importance of distinguishing between popping threshold and ordinary threshold was apparent from the beginning of the current study. A high contrast, low spatial frequency, low temporal frequency (triangle or sine waveform) stimulus has a well-defined spatial structure, but there is no noticeable pop. However, when the contrast of a low spatial frequency, high temporal frequency grating is set to popping threshold, a pop is conspicuous, even though the spatial structure of the pattern cannot be apprehended.

Experiment 2 was conducted in two stages. Two subjects participated in a pilot stage of experimentation, while five other experimentally naive subjects participated in a second stage. This permitted improvements in the experiment to be incorporated, based on the initial observations made before the major part of the data had been collected. The only change between stages was the addition of two low spatial frequencies (0.16 and 0.33 cpd) and of a high temporal frequency rectangular waveform.

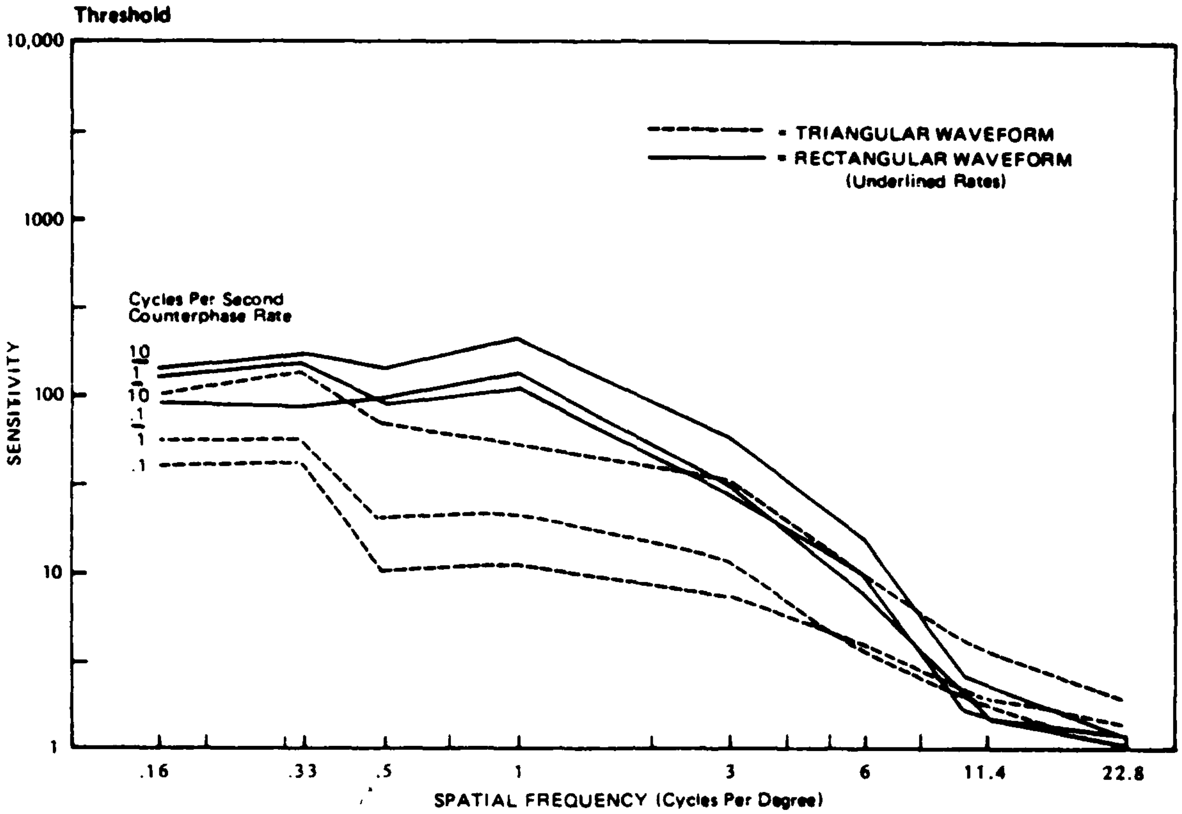
METHOD

STIMULUS AND APPARATUS. Subjects in both stages of the experiment fixated a point 12.5 degrees to the right of the center of the Optronix viewing screen, which subtended 4.4 degrees horizontally at the 3-meter viewing distance. Squarewave gratings of fundamental frequency (0.5, 1.0, 3.0, 6.0, 11.4, 22.8 cycles per degree), which were contrast-modulated as a function of time, with either rectangular or triangular waveforms at various rates, were presented to the two subjects (JA and KB) from stage one. Squarewave gratings were used in this study rather than sinewave gratings, because the former would be more likely to be employed to depict objects having edges and extent or size. In using squarewave gratings, no assumption is required regarding whether the human visual system can be considered to be linear with respect to space. The temporal waveforms were used to model the change in contrast of material of various sizes crossing the blend region at different rates. Rectangular temporal waveforms of 0.1 and 1.0 Hz were used to model a blend region having infinite slope. Triangular temporal waveforms of 0.1, 1.0, and 10 Hz were used to model material moving across a five-degree-wide contrast blend region at rates of 1, 10, and 100 degrees per second assuming trough to peak contrast change for counterphase corresponds to change in contrast across the blend region. (Of course, for other blend region widths, the triangular waveforms map into other rates. For example, for a one-degree-wide blend region, the above rates would correspond to 0.2, 2, and 20 degrees per second.) The five stage-two subjects (BN, BR, CD, DS, KT) also observed gratings of 0.16 and 0.33 cycles per degree of fundamental frequency, and rectangular temporal waveforms of 10 Hz.

PROCEDURE. The experiment was conducted in blocks, with each block including all spatial frequencies; so that for all subjects, each block included six trials. (The lowest spatial frequencies (0.16 and 0.33) were run in a separate block, because a different viewing distance--one meter--was required.) The factorial combination of the six highest temporal frequencies, temporal waveform and response measures (threshold vs rating) resulted in ten blocks of trials for the first two subjects and 12 blocks of trials for the last five subjects. The difference in the number of blocks reflects the addition of the 10 Hz rectangular temporal waveform to the last five subjects. The order of blocks was random (different for each subject), but the order of presentation of spatial frequencies within each block was not. For popping threshold blocks, subjects used the method of adjustment--adjusting peak contrast to the point at which popping was just noticeable. For the rating procedure, subjects judged the degree of popping, using a seven-point rating scale, exhibited by patterns having a constant peak contrast of 0.5. They were instructed to rate most eye-catching or conspicuous patterns as 7, the least as 1, and to use numbers in between to indicate intermediate levels of popping. Each block of trials required approximately ten minutes. Several blocks (usually three) were completed in a single session.

RESULTS AND DISCUSSION

Results of Experiment 2 are presented in Figures 2 and 3, and in Appendix B. Since five of the seven subjects participated in more conditions than the other two, the data have been analyzed and plotted in two ways. First, the data for the five naive subjects who participated in the more extensive design were considered. Secondly, data were analyzed for only those conditions in which all seven subjects participated. Figure 2 shows popping sensitivity (top graph) and ratings of



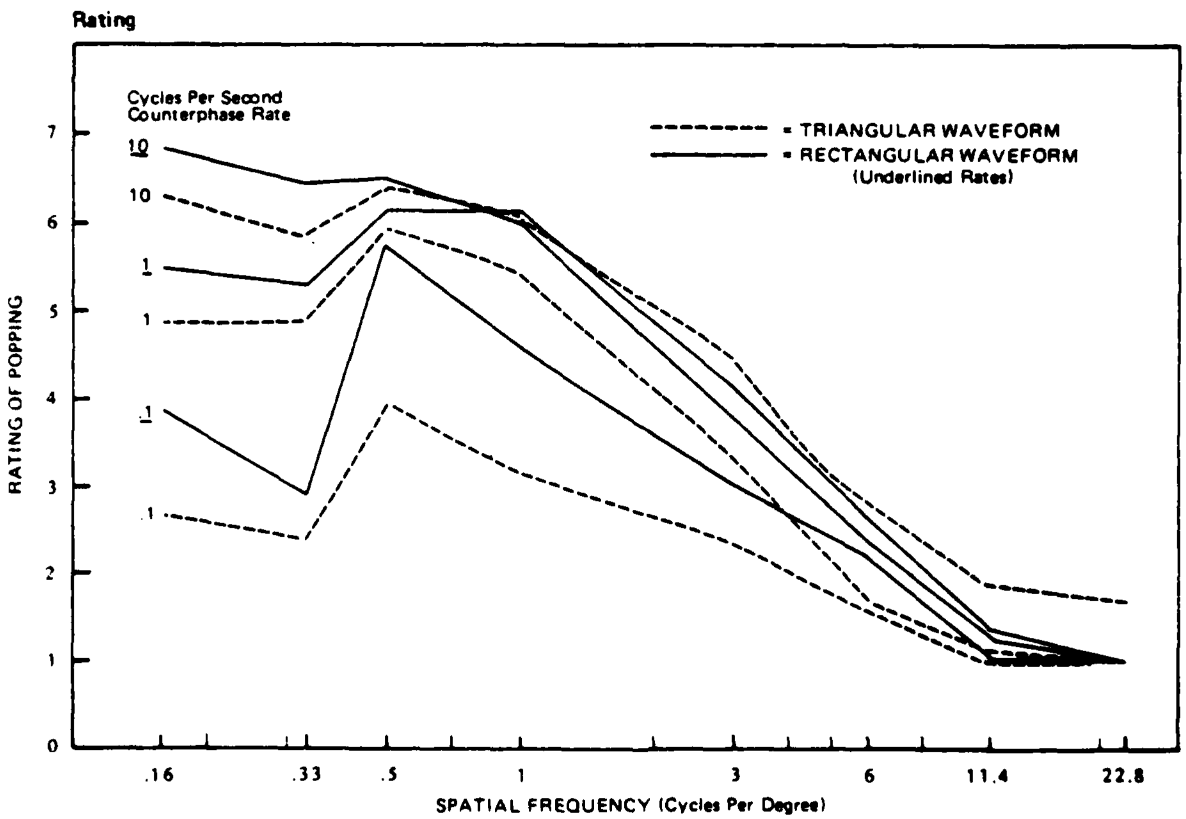


Figure 2. Popping Experiments.

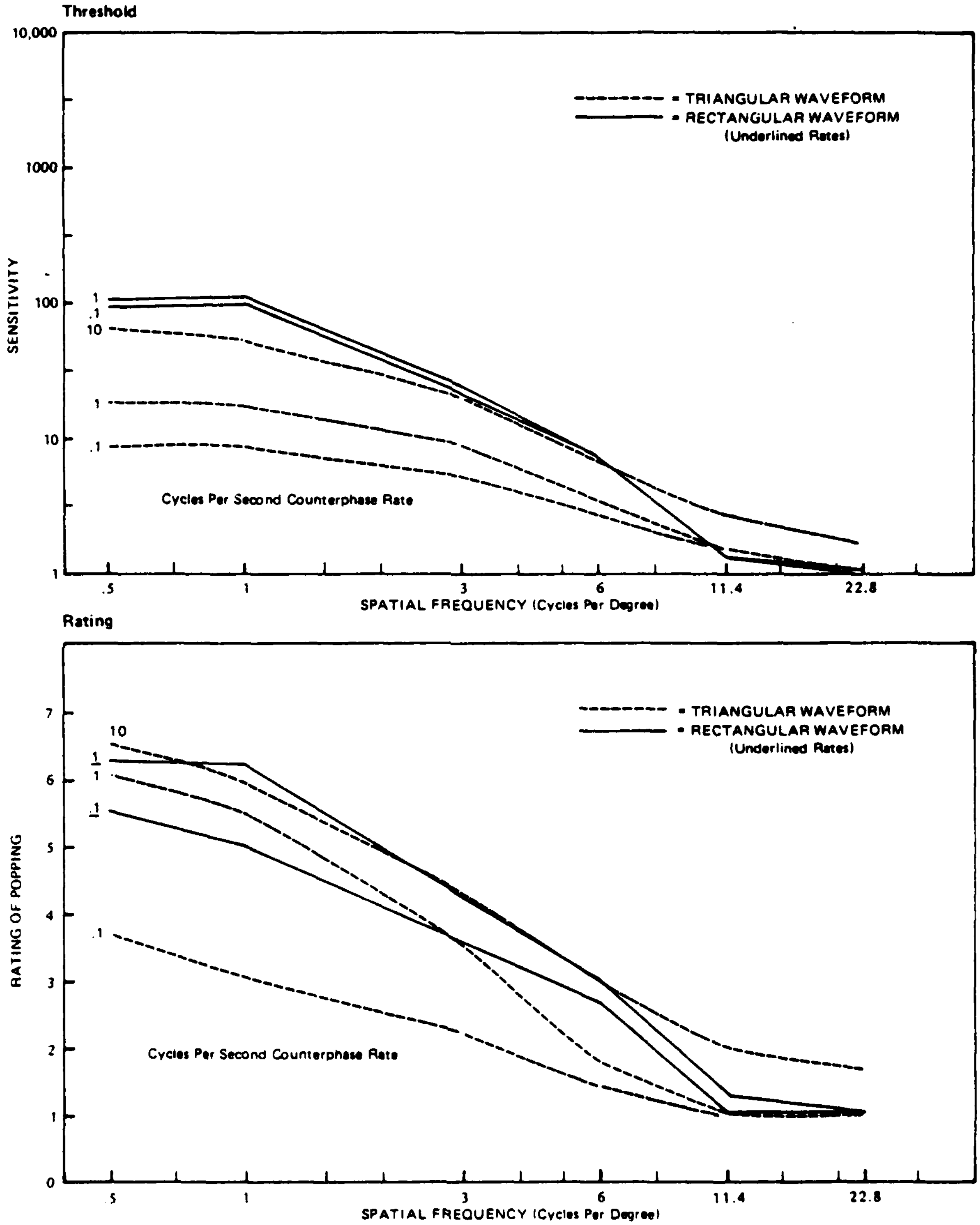


Figure 3. Popping (7 Ss).

popping for five subjects, and Figure 3 shows sensitivity and ratings for seven subjects. Supporting information is provided in Appendix B. The raw data from the experiment are listed in Tables B-4 to B-14 of the Appendix. Figures B-8 through B-10 are graphs of individual subject data: Figure B-8 shows static contrast sensitivity functions; Figure B-9 shows popping threshold, and Figure B-10 shows ratings of popping. Tables B-4 through B-7 of Appendix B present four ANOVA's. The first two are for five subjects; the second two are for seven subjects. Each pair includes one ANOVA for threshold and one for rating. All variables are within subject in these analyses. While the data for the five versus seven subjects appear to be fairly similar, there are important differences. Discussions will focus on the data for five subjects, since the variables are more extensively explored and the experimental design more complete.

Figure 2 contains the key results of this report. In the threshold graph, it is dramatically clear that popping declines with increasing fundamental spatial frequency for all functions ($F=453.46$, $p<.001$). Since the spatial waveform is square, we may also infer that the popping declines with size. Next, consider the order of the functions. If the slope of the onset/offset were the sole variable affecting the order of these functions, then we would expect the following: 1) The functions for rectangular temporal waveform (solid lines) would not differ, since they all have the same onset/offset slopes, though they differ in modulation frequency. 2) The functions for triangular temporal waveform (dashed lines) ought to be separated from each other, with level of popping corresponding to modulation frequency (since for the triangular waveform, onset/offset slope is related to frequency). 3) We would expect the highest temporally modulated triangular waveform function to be just slightly below the rectangular waveform functions, because its onset/offset slope approaches those of the rectangular waveforms (infinity). 4) Statistically, we would expect a main effect for waveform and an interaction between waveform and modulation frequency. These are the sorts of results that we expected after testing two subjects, and appeared to occur when we graphed the original experimental conditions only (see Figure 3). However, the addition of the high temporal frequency rectangular waveform condition (which completes a factorial design) yields some results that are not in complete agreement with these expectations. Of course, many of the expected relationships can be observed visually in the graph for threshold in Figure 2. The overall height of functions seems to depend upon the slope of the change in contrast; those functions with the highest onset/offset slopes overlap, and functions with shallower slopes are correspondingly lower. However, the statistical analysis (see Table B-4) evidences significant main effects for both temporal waveform ($F=25.71$, $p<.01$) and modulation frequency ($F=16.25$, $p<.005$), but no statistically significant interaction between variables.

This means that while onset/offset slope (a contrast blend region) has an impact upon the noticeability of changes in details; the frequency of changes in detail also affects noticeability.

The graph for ratings of popping in Figure 3 shows the sort of results we expected from seven subjects, after collecting data from the first two subjects. We expected the results for ratings of popping to reflect the popping threshold results, with more weight possibly allotted to modulation frequency. The addition of the sixth waveform/modulation condition to complete the experimental design yielded a somewhat different outcome. Statistically significant main effects were obtained for spatial frequency ($F=102.06$, $p<.001$). The lack of a main effect for waveform was unexpected. Of course, it is still possible to argue that onset/offset yields the statistically significant interaction of waveform and modulation frequency ($F=16.42$, $p<.005$) and the greater separation of functions for triangular waveform than for rectangular waveform function (see Figure 2). From these results it is clear that considerably more weight is given to frequency of detail change than to abruptness of detail change than we might expect from the threshold data.

In summary, the suddenness in detail change (onset/offset slope), and the rate of such changes, both affect the threshold and judgmental magnitude of popping. These results indicate that popping declines with: 1) decreasing size, and 2) decreasing onset/offset slope. (There is at least one report in the literature to support this finding; viz. Breitmeyer & Julesz, 1975.) Several conclusions seem warranted. First, a five-degree-wide contrast ramp between area-of-interest and immediate field of view will tend to suppress popping (this tendency being most pronounced at lower rates of travel of material across the blend region). Second, a restriction upon scene modeling which may be helpful in mitigating popping is to maintain contours between levels of detail which represent the external borders and cast shadows of objects. Addition or subtraction of internal contours (smaller detail) should produce much less popping.

SECTION IV

EXPERIMENT 3

A DEMONSTRATION OF ADAPTATION TO POPPING

In Section III of this report, we present a demonstration which in part replicates experiments in the adaption literature in a way that is specific to popping in area-of-interest displays. It is included here more to emphasize the relevance of adaptation than to systematically investigate adaptation phenomena. In the course of collecting the data for the first section of this report, it became clear to us that visual adaptation occurred whenever high contrast stimuli were observed for more than a few seconds. Selective visual adaptation occurs when sensitivity to a test stimulus declines after exposure to an adapting stimulus. In general, the greater the similarity between adapting and test patterns, the greater the adaptation. Selective adaptation to particular sizes at particular retinal locations has been demonstrated by Blakemore and Campbell (1969). Sekuler and Ganz have shown a direction-specific adaptation effect. Perhaps of greatest interest for current purposes is the work of Pantle and Sekuler (1968), Pantle (1970), and Breitmeyer (1973). Pantle and Sekuler reported velocity-specific adaptation in which the reduction in sensitivity depended upon similarity in the velocities of the adapting and test stimuli. Pantle's work and Breitmeyer's work both show that during adaptation, spatial frequency and velocity interact. These reports, taken together, suggest that sustained and transient visual channels may be adapted separately (see also Regan, 1982). (Recall that transient mechanisms respond selectively to high temporal frequency and low spatial frequency, and that sustained mechanisms respond selectively to low temporal frequency and high spatial frequency.) Pantle (1970) used test stimuli of constant spatial frequency, but varied in velocity, and stationary adapting stimuli that varied in spatial frequency. (All gratings were sinewave.) Visibility of high velocity test targets was degraded most by adaptation to low spatial frequency, stationary gratings. Breitmeyer (1973) did a complementary experiment. Adaptation to high velocity targets raised threshold for low spatial frequency stationary gratings most, and adaptation to slow moving targets raised threshold for high spatial frequency stationary gratings most (see Sekuler, 1973, for an excellent review).

Adaptation may be important for eye-coupled area-of-interest displays in two ways. First, exposure to objects that pop into view could reduce sensitivity to later popping, if earlier and later objects crossing the blend region were of the same size and velocity. Secondly, adaptation to popping stimuli may reduce the visibility of non-popping stationary objects. Such adaptation could hinder performance of some visual tasks (such as search).

We, therefore, formulated the following demonstration of adaptation of the type that may be expected to result when detail changes contrast as it crosses the blend region. The same triangular waveforms and viewing conditions as Experiment 2 were used for the current experiment. Six combinations of adapting and test pattern used in the experiment are shown in Appendix C and Table 1. The adaptation period lasted one minute. The response measure was contrast threshold as measured by method of adjustment. In general, adaptation was obtained (though only the first two cases where the stimuli are identical appear to be statistically significant). In general, the magnitude of the effect produced here was about 0.5 log units reduction in threshold sensitivity.

TABLE 1. ADAPTATION T-TESTS
(Triangular Temporal Waveforms--One-Minute Adpaptation)

Cond	Adapting Stimulus: Spa Freq/Temp Freq	Test Stimulus: Spa Freq/Temp Freq	n	$\overline{X}$ (log threshold)	SD_x (log threshold)	$\overline{Y}$ (log threshold)	SD_y	t	df	p
1	.5/1	.5/1	5	-1.26	.16	- .84	.22	7.23	4	<.01
2	.5/10	.5/10	5	-1.75	.26	-1.11	.10	6.67	4	<.01
3	.5/1	3/1	5	- .81	.12	- .62	.15	1.92	4	ns
4	.3/1	.5/1	5	-1.15	.14	-1.04	.18	1.59	4	ns
5	.5/1	.5/10	5	-1.67	.21	-1.59	.20	1.34	4	ns
6	.5/10	.5/1	5	-1.22	.06	-1.01	.30	1.59	4	ns

In summary, we demonstrated adaptation to contrast ramping of the kind explored in Experiment 2. We noted that adaptation may be helpful in reducing popping, but may also reduce sensitivity to patterns that are important in piloting an aircraft.

SECTION V

EXPERIMENT 4

THE AFFECT OF ATTENTIONAL LOAD ON POPPING

In the current section, we take up the questions of how attention may affect or be affected by popping. In the first three experiments, no explicit consideration of workload had been made. It has been recognized (Leibowitz et al., 1982) that a peripheral load (where popping occurs) can inhibit foveal information processing. The possible interference of popping upon other tasks was addressed by attempting to discover ways in which to prevent the perceptual registration of a pop. We operationally defined less registration of popping as less possible interference. Another way to address the question of interference would be to employ a secondary mental task in the presence and absence of popping, and measure the extent of the change in performance. Unfortunately, there are several reasons why such an experiment would be difficult to conduct. First, there are a variety of tasks to consider. Popping will probably interfere with the performance of some visual tasks (visual search for moving targets) more than others. If the task requires attention to objects undergoing popping, then much greater interference would be expected. For this situation, popping of objects and detail could be considered as noise that could obscure the signal of interest. Secondly, and more importantly, it would be difficult to present popping objects over so great an area as would be required without the actual proposed display system itself. Given these difficulties, we attempted to discover how to suppress the effect, rather than measure how great its distracting effect might be. (See recommendations at the end of Experiment 2.)

The other question is whether selective attention to a foveal task might cause the blend region to be ignored so as to render whatever popping occurs less noticeable. Previous experiments had no foveal loading; subjects fixated 12.5 degrees to the side of the center of the Optronix screen, but visual attentional resources were allocated to the screen. There is some evidence that loading the center of vision with a difficult task reduces the size of the functional visual field (Webster & Haselrud, 1964; Ikeda & Takeuchi, 1975). It could be that a center task loading would collapse the popping threshold and popping noticeability functions.

To test this hypothesis we contrived a viewing situation in which foveal workload could be varied. The viewing conditions were the same as those of Experiments 1 and 2, except for the substitution of a color video monitor for the fixation point of the previous experiments. Subjects fixated the center of the color monitor, and in half of the experimental conditions were mentally occupied by a video game played on this screen. The game involved the continuous presentation of four colored squares, one in each quadrant of the screen. These squares are "lighted" one at a time in a sequence producing strings of five lights in random order. The lights were intensified for a duration of 0.3 seconds, and 0.6 seconds intervened between successive intensifications. The subjects' task was to duplicate the sequence just observed on the screen using a joystick and screen cursor. As soon as duplication was completed by the subject, a new sequence was generated and presented on the screen. This task requires continuous and substantial attention to the screen, in order to observe and duplicate the sequences. The viewing screen of the Optronix Vision Tester was centered 12.5 degrees to the right of the center of the video game screen. Attentional load and no-load conditions were generated by having the experimental subject play the game in the attentional load condition, and having the experimenter play the game in the no-load condition. This manipulation was combined with temporal modulation and spatial frequencies of gratings appearing on the Optronix screen to form a 2x2x3 factorial design. Seven subjects participated in the experiment. Triangular waveforms were used to modulate all gratings. Method of increasing limits was used to measure contrast threshold to the gratings, primarily because it requires the simplest response available in the Optronix: a simple button press to indicate detection of the grating. For each trial of the experiment, peak stimulus contrast was increased from zero to five in 30 seconds. No preview was used. The response key was pressed with the subject's foot, rather than hand, in order to minimize response competition. The kev press terminated the contrast of the test grating.

The results of this experiment are presented in Figure 4 and Appendix D. The appendix includes raw data, graphs of individual subjects data, and an analysis of variance. Though statistically significant main effects were obtained for temporal modulation frequency and for spatial frequency, there was no main effect for attentional load. These results are in agreement with reports made by subjects at the end of the experiment. The popping is as apparent with attentional load as without.

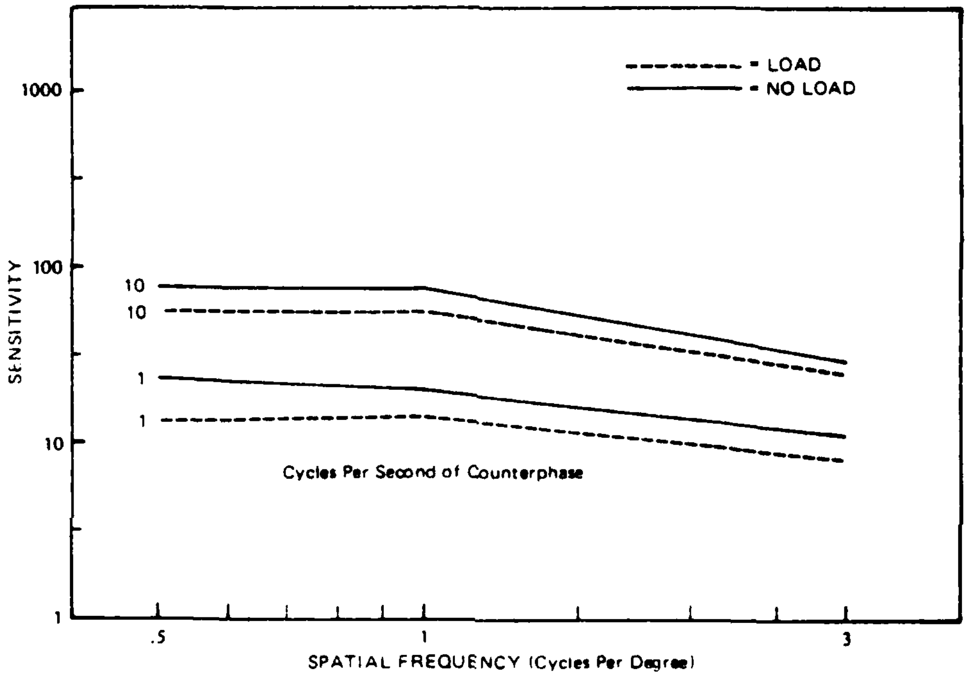


Figure 4. Attention.

There are several methodological problems with this study. A major problem is response competition. Subjects might have had to respond to the grating when they were either trying to rehearse a visual sequence or duplicate a sequence by moving the cursor over the four patches of light on the color monitor. This could result in a delay in responding to indicate detection of the grating, due to response competition, which would tend to elevate threshold in the attentional load condition. Such an artifact, had it been obtained, would have been rather embarrassing to explain. (Note that there appears to be a small effect in Figure 4; however, the difference is, as noted, nonsignificant and too small to be of practical interest, in any case.)

Our conclusion is that attentional loading of the fovea will be of little help in suppressing popping.

SECTION VI

RECOMMENDATIONS

FURTHER RESEARCH ON THROUGHPUT DELAY AND COLOR

The experiments reported assume a zero or very small throughput delay. When the lag in centering the area of interest upon the position of eye fixation becomes substantial, then the area of interest will "trail" eye movements. The impact of this would be for the blend region to occur at retinal eccentricities other than those explored in this report. In fact, in overtaking a saccadic eye movement, the blend region would actually sweep across the fovea. Thus, our findings are valid for stationary viewing and pursuit eye movements, but probably less for ballistic (saccadic) eye movements.

In changing levels of details, it would be desirable to have smooth, continuous change in contrast and position. The impact of adding and subtracting details of colors contrasting greatly with the immediate surround ought to be checked. It may be more difficult to produce smooth and continuous change in color than smooth and continuous changes in form or shape (Kolers and Von Grunau, 1976; Carter and Carter, 1981). Of course, the importance of color will depend upon retinal locus.

NOTES

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PRELIMINARY EXPERIMENTS

TABLE A-2. LOG THRESHOLD CONTRAST RAW DATA

SUBJECT: JA

Contrast Sensitivity

Eccent	Motion	.5	1	2	6	11.4	22.8
0	0	-1.476	-2.344	-2.465	-2.45	-2.627	-1.112
0	0	-2.059	-2.579	-2.473	-2.781	-1.996	na
0	3	-2.38	[illegible]	[illegible]	-2.001	na	na
0	5	-2.564	[illegible]	[illegible]	na	na	na
10	0	-1.293	[illegible]	[illegible]	-1.654	- .577	.0
10	1	-1.603	[illegible]	[illegible]	-1.515	.0	na
10	3	-1.755	[illegible]	[illegible]	- .751	na	na
10	5	-1.96	[illegible]	[illegible]	na	na	na
15	0	- .854	[illegible]	[illegible]	- .867	.0	.0
15	1	-1.345	[illegible]	[illegible]	- .894	.0	na
15	3	-1.441	[illegible]	[illegible]	- .37	na	na
15	5	-1.711	[illegible]	[illegible]	na	na	na

SUBJECT: KB

Contrast Sensitivity

Eccent	Motion	.5	1	2	6	11.4	22.8
0	0	-1.445	[illegible]	[illegible]	-2.669	-2.18	-1.131
0	1	-2.151	[illegible]	[illegible]	-2.708	-1.887	na
0	3	-2.429	[illegible]	[illegible]	-1.839	na	na
0	5	[illegible]	[illegible]	[illegible]	na	na	na
10	0	-1.324	[illegible]	[illegible]	1.392	- .386	.0
10	1	[illegible]	[illegible]	[illegible]	-1.264	.0	na
10	3	[illegible]	[illegible]	[illegible]	- .682	na	na
10	5	[illegible]	[illegible]	[illegible]	na	na	na
15	0	-1.149	[illegible]	[illegible]	- .415	.0	.0
15	1	[illegible]	[illegible]	[illegible]	- .436	.0	na
15	3	-1.617	[illegible]	[illegible]	- .377	na	na
15	5	-1.651	[illegible]	[illegible]	na	na	na

TABLE A-3. COUNTERPHASE LOG THRESHOLD RAW DATA

SUBJECT: KB

Counterphase (Temporal sinewave)

Eccent	Hz	.1	.5	1	3	6	11.4	22.8
0	1	-1.894	-2.189	-2.462	-2.519	-2.34	-2.089	- .985
0	5	-1.989	-2.398	-2.592	-2.426	-2.162	-1.977	-1.101
0	10	-1.845	-2.162	-2.379	-2.389	-2.001	-1.416	- .449
0	25	-1.591	-1.634	-1.68	-1.571	-1.722	-1.599	-1.001
10	1	-1.354	-1.594	-1.843	-1.854	-1.359	- .327	- .0
10	5	-1.695	-2.006	-2.114	-2.007	-1.146	- .314	- .314
10	10	-1.534	-1.811	-1.924	-1.839	- .416	.0	.0
10	25	-1.369	-1.625	-1.631	-1.199	- .45	-	-
15	1	-1.322	-1.649	-1.686	-1.332	- .389	.0	.0
15	5	-1.458	-1.719	-1.879	-1.461	- .43	- .305	-
15	10	-1.599	-1.934	-1.889	-1.121	-	-	-
15	25	-1.422	-1.619	-1.572	- .747	-	-	-

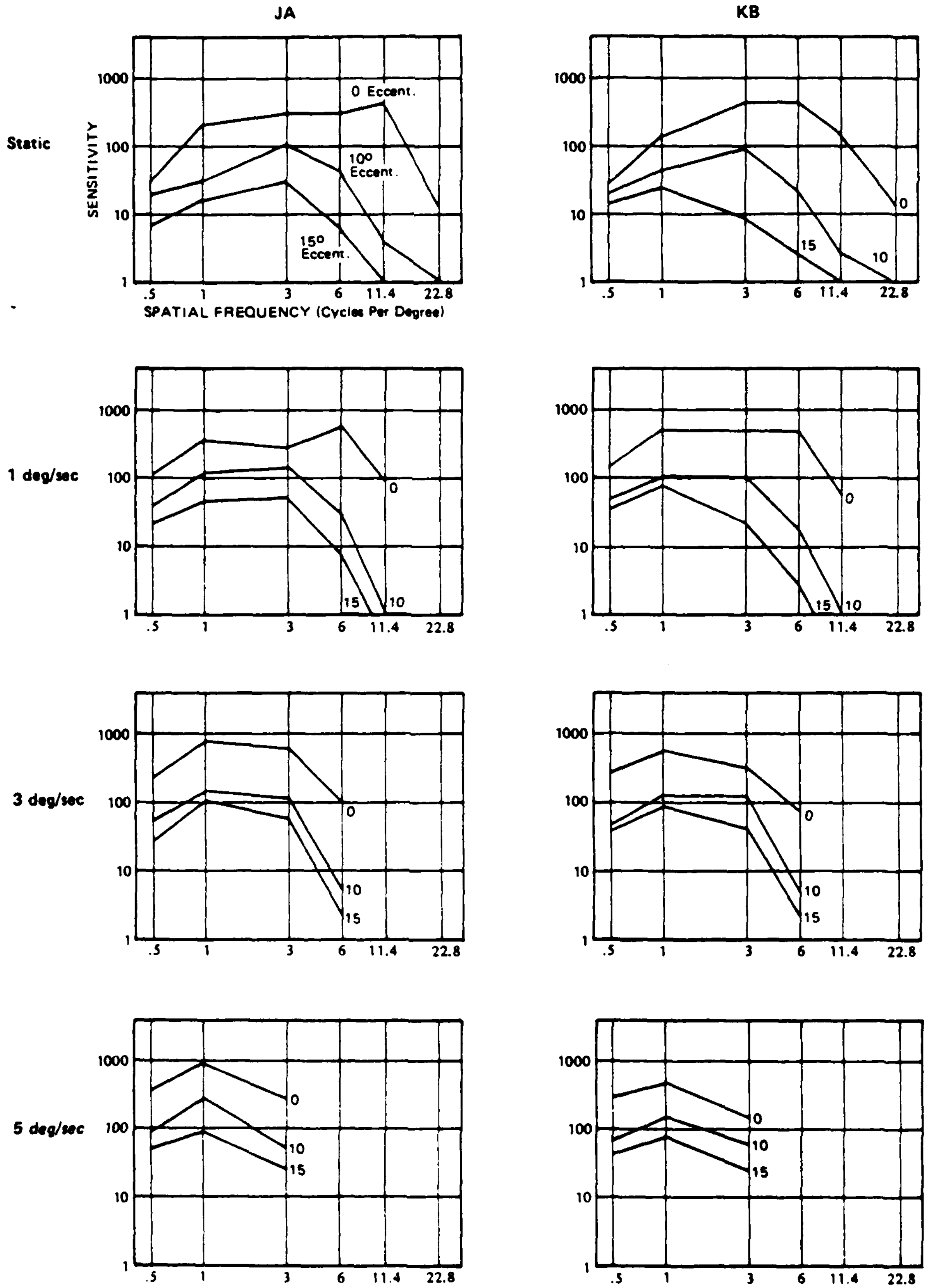

Figure A-5. Contrast Sensitivity.

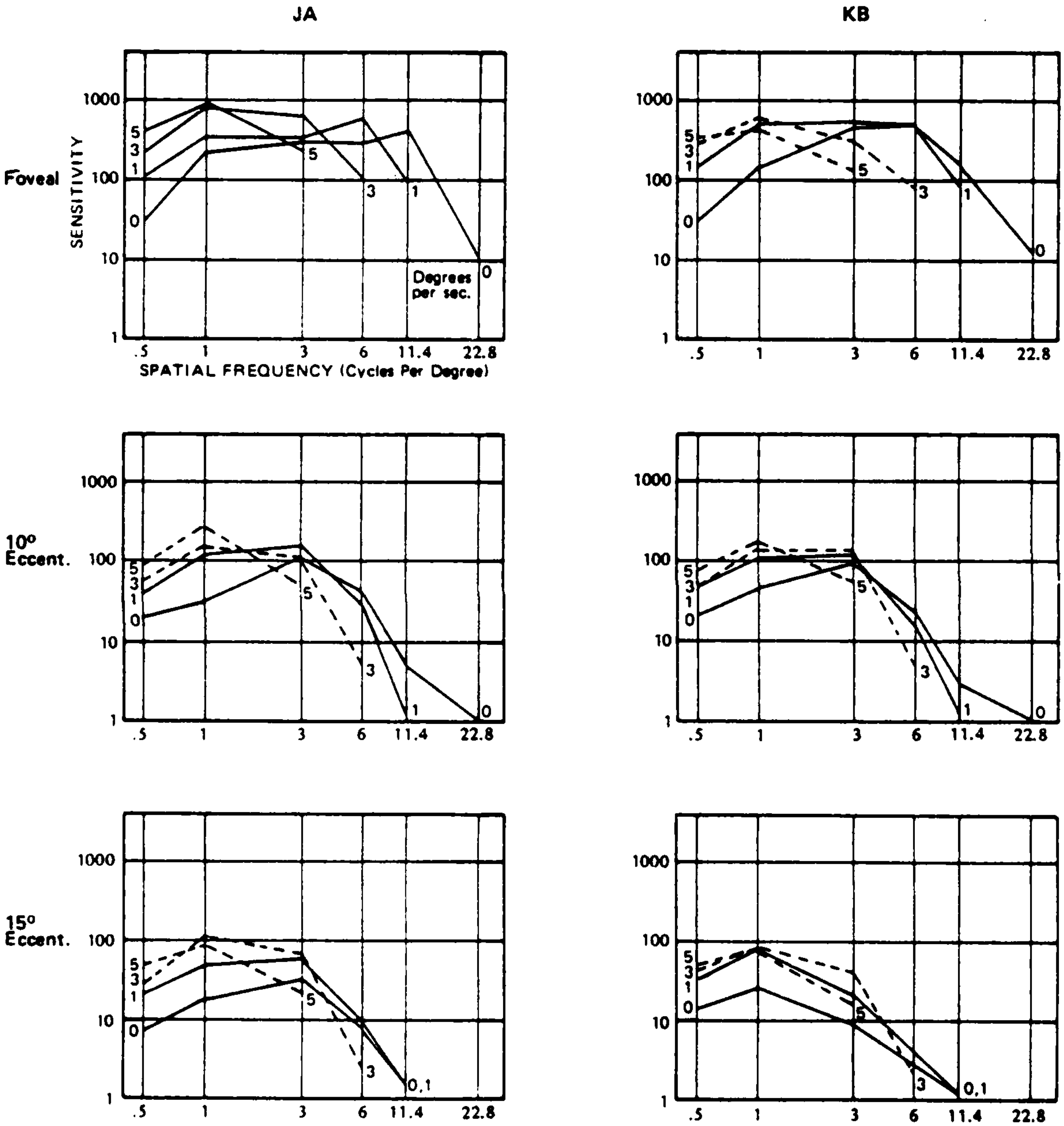

Figure A-6. Contrast Sensitivity.

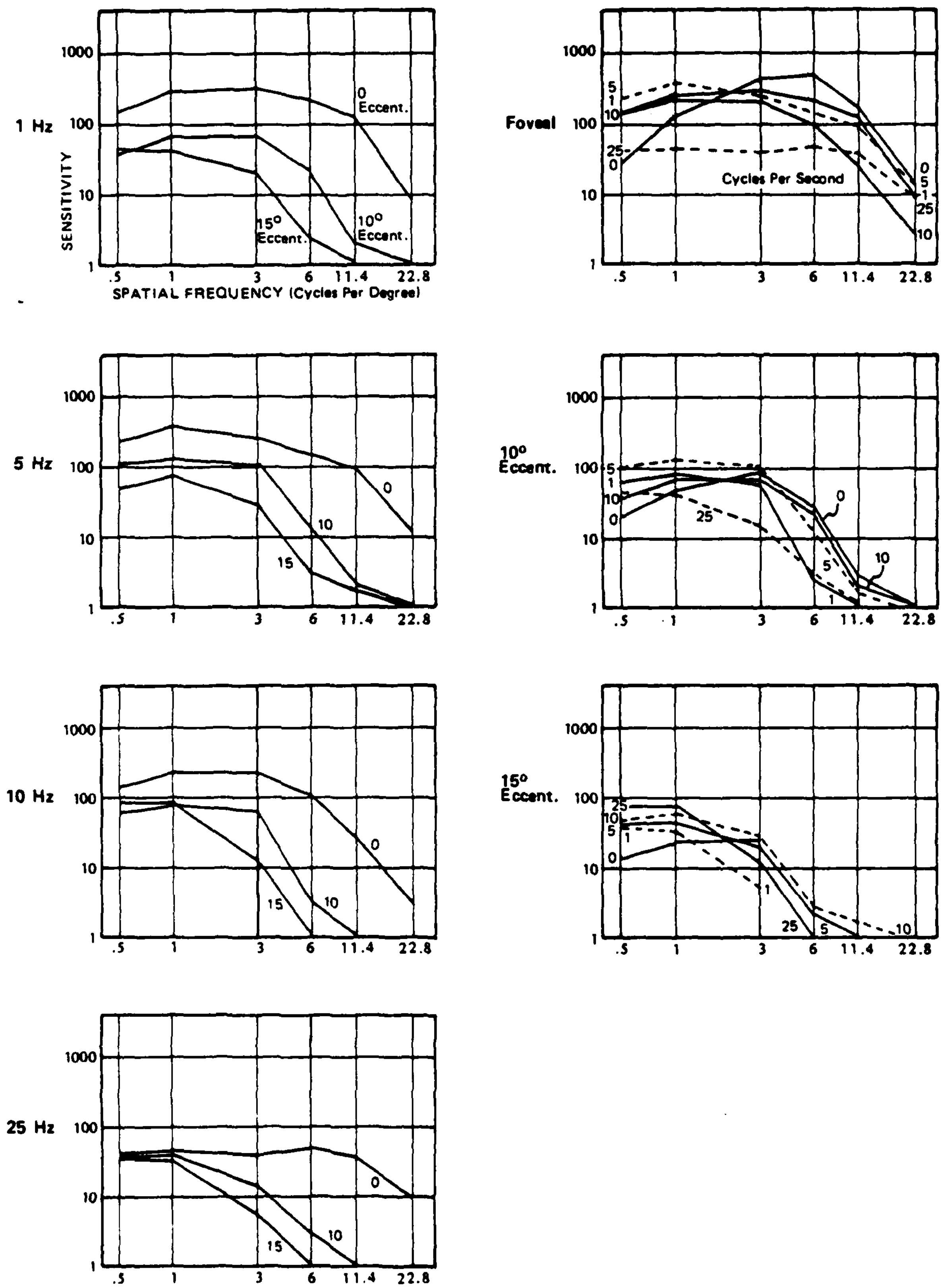

Figure A-7. Counterphase Contrast Sensitivity (KB).

APPENDIX B

SIZE AND TEMPORAL WAVEFORM EXPERIMENTS

TABLE B-4. ANOVA AND MARGINAL MEANS - POPPING THRESHOLD - 5 SUBJECTS (See data in Figure 2 and Figure B-9)

ANOVA

Source of Variation	Sums of Squares	df	Mean Squares	F Ratio	p Value
Temporal Waveform	5.922	1	5.922	25.709	p<.01
Temporal Frequency	5.2472	2	2.6236	16.251	p<.005
Spatial Frequency	115.9515	7	16.5645	453.464	p<.001
Waveform * Frequency	0.9276	2	0.4638	3.969	ns
Waveform * Spatial	5.1202	7	0.7314	15.464	p<.001
Frequency * Spatial	0.6397	14	0.0495	1.173	ns
W * S * F	0.5651	14	0.0403	1.318	ns
Waveform Error	0.9213	4	0.2303		
Frequency Error	1.2915	8	0.1614		
Spatial Error	1.0228	28	0.0365		
W * F Error	0.9347	8	0.1168		
W * S Error	1.3243	28	0.0472		
F * S Error	2.3643	56	0.0422		
W * S * F Error	1.7149	56	0.0306		
TOTAL	145.5226	239			

Means (in log threshold)

Temporal Waveform

Square	-1.41
Triangle	-1.10

Temporal Frequency

.1 c/s	-1.11
1. c/s	-1.20
10. c/s	-1.46

Spatial Frequency

.16 c/d	-1.93
.33 c/d	-1.98
.5 c/d	-1.71
1. c/d	-1.77
3. c/d	-1.37
6. c/d	- .87
11.4 c/d	- .31
22.8 c/d	- .09

(cont'd)

TABLE B-4. ANOVA AND MARGINAL MEANS -
POPPING THRESHOLD - 5 SUBJECTS (cont'd)

Temporal Waveform * Spatial Frequency

	Square	Triangle
.16	-2.Ø7	-1.79
.33	-2.12	-1.85
.5	-2.Ø4	-1.38
1.	-2.16	-1.38
3.	-1.58	-1.16
6.	-1.Ø3	- .72
11.4	- .26	- .36
22.8	- .Ø4	- .14

TABLE B-5. ANOVA AND MARGINAL MEANS
POPPING RATINGS - 5 SUBJECTS
(See data in Figure 2 and Figure B-10)

ANOVA

Source of Variation	Sums of Squares	df	Mean Squares	F Ratio	p Value
Temporal Waveform	6.6001	1	6.6001	2.808	ns
Temporal Frequency	124.561	2	62.2805	102.06	$p<.001$
Spatial Frequency	709.7118	7	101.3874	178.878	$p<.001$
Waveform * Frequency	9.565	2	4.7825	16.418	$p<.005$
Waveform * Spatial	6.7171	7	0.9595	5.745	$p<.001$
Frequency * Spatial	56.3569	14	4.0254	11.297	$p<.001$
W * S * F	5.8155	14	0.4153	3.197	$p<.005$
W Error	9.3994	4	2.3498		
F Error	4.8818	8	0.6102		
S Error	15.8702	28	0.5667		
W * F Error	2.3303	8	0.2912		
W * S Error	4.6765	28	0.167		
F * S Error	19.9534	56	0.3563		
W * S * F Error	7.2756	56	0.1299		
TOTAL	990.7118	239			

Means (1-7 Rating Scale)

Temporal Waveform	
Square	3.78
Triangle	3.45

Temporal Frequency	
.1 c/s	2.66
1. c/s	3.80
10. c/s	4.39

Spatial Frequency	
.16 c/d	5.04
.33 c/d	4.65
.5 c/d	5.73
1. c/d	5.25
3. c/d	3.55
6. c/d	2.29
11.4 c/d	1.29
22.8 c/d	1.11

Temporal Waveform * Temporal Frequency

	Square	Triangle
.1	3.02	2.30
1.	4.04	3.55
10.	4.28	4.500

TABLE B-5. ANOVA AND MARGINAL MEANS
POPPING RATINGS - 5 SUBJECTS (cont'd)

Temporal Waveform * Spatial Frequency

	Square	Triangle
.16	5.42	4.66
.33	4.89	4.41
.5	6.01	5.45
1.	5.59	4.91
3.	3.66	3.43
6.	2.43	2.15
11.4	1.24	1.35
22.8	1.00	1.23

Temporal Frequency * Spatial Frequency

	1	1	10
.16	3.1	5.20	6.61
.33	2.68	5.08	6.19
.5	4.68	6.05	6.46
1.	3.91	5.81	6.03
3.	2.72	3.78	4.14
6.	1.91	2.18	2.78
11.4	1.03	1.27	1.58
22.8	1.00	1.00	1.34

TABLE B-6. ANOVA AND MARGINAL MEANS -
POPPING THRESHOLD - 7 SUBJECTS
(See data in Figure 3 and Figure B-9)

ANOVA

Source of Variation	Sums of Squares	df	Mean Squares	F Ratio	p Value
Temporal Function	10.703	4	2.6757	15.217	p<.001
Spatial Frequency	76.7166	5	15.3433	240.553	p<.001
T * S	6.9582	20	0.3479	10.584	p<.001
T Error	4.2199	24	0.1758		
S Error	1.9135	30	0.0637		
T * S Error	3.9444	120	0.0328		
TOTAL	108.5828	209			

Means (Log Threshold)

Temporal Function

.1 c/s squarewave	-1.08
1. c/s squarewave	-1.06
.1 c/s trianglewave	- .53
1. c/s trianglewave	- .72
10. c/s trianglewave	-1.07

Spatial Frequency

.5 c/d	-1.60
1. c/d	-1.60
3.	-1.15
6. c/d	- .71
11.4 c/d	- .22
22.8 c/d	- .08

Temporal Function * Spatial Frequency

	.1 Hz Sq	1 Hz Sq	.1 Hz Tri	1 Hz Tri	10 Hz Tri
.5	-2.01	-1.98	-.92	-1.25	-1.81
1.	-2.05	-2.00	-.93	-1.24	-1.72
3.	-1.38	-1.35	-.72	- .96	-1.32
6.	- .87	- .88	-.43	- .55	- .85
11.4	- .13	- .15	-.19	- .20	- .44
22.8	- .05	- .00	-.00	- .10	- .25

TABLE B-7. ANOVA AND MARGINAL MEANS -
POPPING RATINGS - 7 SUBJECTS
(See Figure 3 and Figure B-10)

Source of Variation	Sums of Squares	df	Mean Squares	F Ratio	p Value
Temporal Function	84.288	4	21.072	16.02	p<.001
Spatial Frequency	653.9924	5	130.7984	282.314	p<.001
T * S	37.5616	20	1.878	7.37	p<.001
T Error	31.5679	24	1.3153		
S Error	13.8992	30	0.4633		
T * S Error	30.5783	120	0.2548		
TOTAL	865.1392	209			

Means (Log Threshold)

Temporal Function

.1 c/s squarewave	-3.13
1. c/s squarewave	-3.67
.1 c/s trianglewave	-2.08
1. c/s trianglewave	-3.17
10. c/s trianglewave	-3.92

Spatial Frequency

.5 c/d	-5.65
1. c/d	-5.17
3. c/d	-3.58
6. c/d	-2.36
11.4 c/d	-1.28
22.8 c/d	-1.13

Temporal Function * Spatial Frequency

	.1 Hz Sq	1 Hz Sq	.1 Hz Tri	1 Hz Tri	10 Hz Tri
.5	-5.54	-6.27	-3.76	-6.07	-6.59
1.	-5.01	-6.24	-3.07	-5.53	-5.99
3.	-3.54	-4.23	-2.21	-3.59	-4.31
6.	-2.63	-3.01	-1.41	-1.73	-3.00
11.4	-1.04	-1.29	-1.00	-1.10	-1.96
22.8	-1.00	-1.00	-1.00	-1.00	-1.66

TABLE B-8. SUBJECTS JA, KB -
POPPING THRESHOLD - RAW DATA

SUBJECT: JA

Popping Threshold (Triangular Waveform)

Hz	Waveform	.5	1	3	6	11.4	22.8
.1	Sq	-2.	-1.91	-1.09	-.7	0	0
1.	Sq	-1.87	-1.86	-1.14	-.58	0	0
.5	Tri	- .83	- .76	- .72	- 0	0	0
1.	Tri	-1.09	-1.07	- .63	-.49	0	0
10.	Tri	-1.73	-1.79	-1.05	-.58	-.39	-.4

SUBJECT: KB

Hz	Waveform	.5	1	3	6	11.4	22.4
.1	Sq	-2.13	-1.8	-1.09	-.95	-	-
1.	Sq	-2.14	-2.01	-1.07	-.62	-	-
.1	Tri	- .52	- .47	.0			
.5	Tri	- .81	- .61	- .39	0		
1.	Tri	-1.11	- .92	- .61	-.43	0	
10.	Tri	-1.7	-1.59	- .94	-.64	-.52	-.54
30.	Tri	-1.86	-1.58	- .63	-.46	0	0

TABLE B-9. SUBJECTS JA, KB - RATING OF POPPING - RAW DATA

SUBJECT: KB

Hz	Wave	.5	1	3	6	11.4	22.8
.1	Tri	2.	1.5	1.1	1.	1.	1.
.5	Tri	4.3	3.3	2.5	1.5	1.	1.
1.	Tri	5.8	5.4	4.6	2.1	1.	1.
10.	Tri	7.	5.6	4.3	3.7	3.2	2.2
.1	Sq	7.	7.	5.6	4.2	1.	1.
.1	Sq	6.1	6.4	4.8	4.8	1.	1.

SUBJECT: JA

Hz	Wave	.5	1	3	6	11.4	22.8
.1	Tri	4.3	4.	2.4	1.	1.	1.
.5	Tri	4.	4.	2.	1.	1.	1.
1.	Tri	7.	6.	3.5	1.5	1.	1.
10.	Tri	7.	6.	3.4	1.5	1.	1.
.1	Sq	5.	5.	4.	3.	1.	1.
1.	Sq	7.	6.5	4.	3.	1.	1.

TABLE B-10. SUBJECT BN - THRESHOLD AND RATING RAW DATA

Threshold

	.16	.33	.5	1	3	6	11.4	22.8
CSF (0)	-1.667	-2.291	-1.627	-2.441	-2.96	-2.396	-2.22	-1.307
CSF (12.5)	-1.425	-1.741	-1.52	-1.922	-2.087	-1.981	-1.385	- .62
Pop								
.1 Hz Sq	-1.94	-1.54	-2.31	-2.61	-1.57	-1.16	- .55	- .32
1. Hz Sq	-2.31	-2.46	-2.08	-1.97	-1.73	-1.19	- .35	- .3
10. Hz Sq	-2.25	-2.31	-2.08	-2.37	-1.71	-1.21	- .71	- .31
.1 Hz Tri	-2.08	-1.57	-1.09	-1.12	- .88	- .68	- .39	- .3
.5 Hz Tri			-1.6	-1.42	-1.01	- .65	- .31	- .3
1. Hz Tri	-2.04	-2.02	-1.29	-1.49	-1.71	- .94	- .61	- .3
10. Hz Tri	-2.25	-2.4	-1.47	-1.38	-1.78	-1.41	- .51	- .42

Rating

Pop								
.1 Hz Sq	4	2	2	6	5	3	2	1
1. Hz Sq	6	6	7	7	4	2	1	1
10. Hz Sq	7	7	6	6	4	2	1	1
.1 Hz Tri	2	2	5	4	3	1	1	1
.5 Hz Tri			5	5	3	2	1	1
1. Hz Tri	5	5	6	6	3	1	1	1
10. Hz Tri	6	6	6	6	4	3	2	2
30. Hz Tri			7	7	5	3	1	1

TABLE B-11. SUBJECT BR - THRESHOLD AND RATING - RAW DATA

Threshold

	.16	.33	.5	1	3	6	11.4	22.8
CSF (0)	-1.395	-1.599	-1.492	-1.789	-2.666	-2.428	-2.256	-1.521
CSF (12.5)	-1.071	-1.393	-1.112	-1.43	-1.588	-1.131	- .696	- .54
Pop								
.1 Hz Sq	-1.94	-2.04	-1.91	-1.86	-1.52	- .71	- .3	- .3
1. Hz Sq	-2.07	-2.19	-1.85	-1.99	-1.13	- .94	- .3	- .3
10. Hz Sq	-2.06	-2.15	-2.21	-2.3	-1.75	-1.25	- .3	- .3
30. Hz Sq								
.1 Hz Tri	-1.67	-1.67	-1.35	-1.41	-1.4	-1.05	- .35	- .3
.5 Hz Tri			-1.29	-1.68	-1.57	- .42	- .3	- .3
1. Hz Tri	-1.81	-1.79	-1.57	-1.39	-1.22	- .46	- .41	- .36
10. Hz Tri	-2.08	-2.2	-2.07	-1.91	-1.84	-1.46	- .36	- .36
30. Hz Tri			-1.73	-1.7	-1.37	- .53	- .3	- .3

Rating

Pop	.16	.33	.5	1	3	6	11.4	22.8
.1 Hz Sq	4.5	3.5	4.5	3.5	2	1.5	1	1
1. Hz Sq	5	5	5.25	5.25	4	2.25	1	1
10. Hz Sq	6.5	5.5	7	6	3	2	1	1
.1 Hz Tri	4.25	3.5	4	3	2	1.7	1	1
.5 Hz Tri			6	4.75	3.5	2.5	1.5	1
1. Hz Tri	5.5	6	6.5	5.5	3.3	1.5	1	1
10. Hz Tri	6	5.25	7	6.5	5.5	4.5	2	2
30. Hz Tri			7	7	5	2.5	1	1

TABLE B-12. SUBJECT CD - THRESHOLD AND RATING - RAW DATA

Threshold

	.16	.33	.5	1	3	6	11.4	22.8
CSF (0)	-1.491	-1.643	-1.383	-2.226	-2.401	-2.294	-2.294	-1.78
CSF (12.5)	- .966	-1.558	-1.306	-1.639	-1.845	-1.605	- .951	--
Pop								
.1 Hz Sq	-2.07	-2.04	-1.97	-2.11	-1.37	- .86	- .37	- .3
1. Hz Sq	-2.13	-2.08	-1.86	-2.03	-1.51	- .99	- .36	- .3
10. Hz Sq	-2.14	-2.24	-2.01	-2.28	-1.7	-1.18	- .38	- .3
30. Hz Sq								
.1 Hz Tri	-1.4	-1.63	-1.41	-1.32	-1.3	-1.13	- .62	- .3
.5 Hz Tri								
1. Hz Tri	-1.72	-1.6	-1.13	-1.16	- .81	- .57	- .3	- .3
10. Hz Tri	-1.88	-2.15	-1.69	-1.76	-1.57	-1.04	- .81	- .61
30. Hz Tri			-1.84	-1.71	-1.41	- .64	- .3	- .3

Rating

	.16	.33	.5	1	3	6	11.4	22.8
Pop								
.1 Hz Sq	4.5	3	6	5	4	3.5	1	1
.1 Hz Sq	6	5	6.5	6.5	5.5	4.5	2.5	1
10. Hz Sq	6.75	6.25	7	6	4	3	1.5	1
.1 Hz Tri	3.25	3	5	4	3	2	1	1
.5 Hz Tri			5.3	4.25	2.5	1.5	1	1
1. Hz Tri	5	4.25	6	5	4	2.5	1.5	1
10. Hz Tri	6.5	5.5	6.25	5.5	4	2.5	2	1.5
30. Hz Tri			6.5	5.5	4	2.25	1	1

TABLE B-13. SUBJECT DW - THRESHOLD AND RATING - RAW DATA

Threshold

	.16	.33	.5	1	3	6	11.4	22.8
CSF (0)	-1.395	-1.789	-1.491	-2.01	-2.446	-2.646	-2.336	-1.329
CSF (12.5)	-1.191	-1.299	-1.197	-1.521	-1.677	-1.202	- .66	--
Pop								
.1 Hz Sq	-1.97	-2.11	-1.82	-2.04	-1.55	- .85	- .3	- .3
1. Hz Sq	-2.02	-2.15	-2.05	-2.05	-1.48	- .78	- .34	- .3
10. Hz Sq	-1.97	-2.09	-2.19	-2.33	-1.73	-1.14	- .39	- .3
30. Hz Sq			-2.04	-1.88	-1.1	- .34	- .3	- .3
.1 Hz Tri	-1.42	-1.76	-1.25	-1.31	- .71	- .45	- .3	- .3
.5 Hz Tri			-1.53	-1.32	- .72	- .42	- .3	- .3
1. Hz Tri	-1.59	-1.76	-1.52	-1.19	- .82	- .51	- .32	- .3
10. Hz Tri	-1.9	-1.91	-2.11	-1.85	-1.36	- .77	- .51	- .33

Rating

Pop								
.1 Hz Sq	3	2.5	5.3	4.6	3.2	2.2	1.3	1
1. Hz Sq	4.5	4.5	6	6	4	2.5	1.25	1
10. Hz Sq	7	6.5	6.5	6	4.25	2.5	1.5	1
.1 Hz Tri	2	2	4	3.75	3	2.2	1	1
.5 Hz Tri			5.4	5.3	3.7	2.2	1.25	1
1. Hz Tri	4	4.5	6.2	6	4	2.3	1.2	1
10. Hz Tri	6.5	6.25	6.8	6.5	5	3	2	1.7
30. Hz Tri			6.7	6.4	5	2.8	1.2	1

TABLE B-14. SUBJECT KT - THRESHOLD AND RATING - RAW DATA

Threshold

	.16	.33	.5	1	3	6	11.4	22.8
CSF (0)	-2.297	-2.464	-1.361	-2.082	-2.579	-2.69	-2.17	-1.534
CSF (12.5)	-1.932	-2.089	-1.137	-1.486	-1.87	-1.355	- .366	--
Pop								
.1 Hz Sq	-1.92	-1.96	-1.96	-2.01	-1.47	- .86	- .3	- .3
1. Hz Sq	-2.03	-2.11	-2.03	-2.1	-1.42	-1.04	- .3	- .3
10. Hz Sq	-2.16	-2.29	-2.31	-2.33	-2.02	-1.22	- .49	- .3
30. Hz Sq								
.1 Hz Tri	-1.48	-1.48	- .3	- .3	- .3	- .3	- .3	- .3
.5 Hz Tri			- .86	-1.01	- .74	- .39	- .3	- .3
1. Hz Tri	-1.56	-1.56	-1.33	-1.37	-1.01	- .48	- .35	- .35
10. Hz Tri	-1.98	-2.18	-2.15	-2.15	-1.52	- .98	- .63	- .34
30. Hz Tri			-1.72	-1.64	-1.02	- .41	- .3	- .3

Rating

Pop

	.16	.33	.5	1	3	6	11.4	22.8
.1 Hz Sq	3.5	3.5	5	5	3	2	1	1
1. Hz Sq	6	6	6	6	3.3	2	1.2	1
10. Hz Sq	7	7	6	6	3.6	2.5	1.3	1
.1 Hz Tri	2	1.75	2	1.2	1	1	1	1
.5 Hz Tri			4.3	4	1.8	1.2	1	1
1. Hz Tri	5	4.5	5	4.8	2.7	1.2	1	1
10. Hz Tri	6.75	6.5	6	5.8	4	2.8	1.5	1.2
30. Hz Tri			5.8	5.7	3	2	1	1

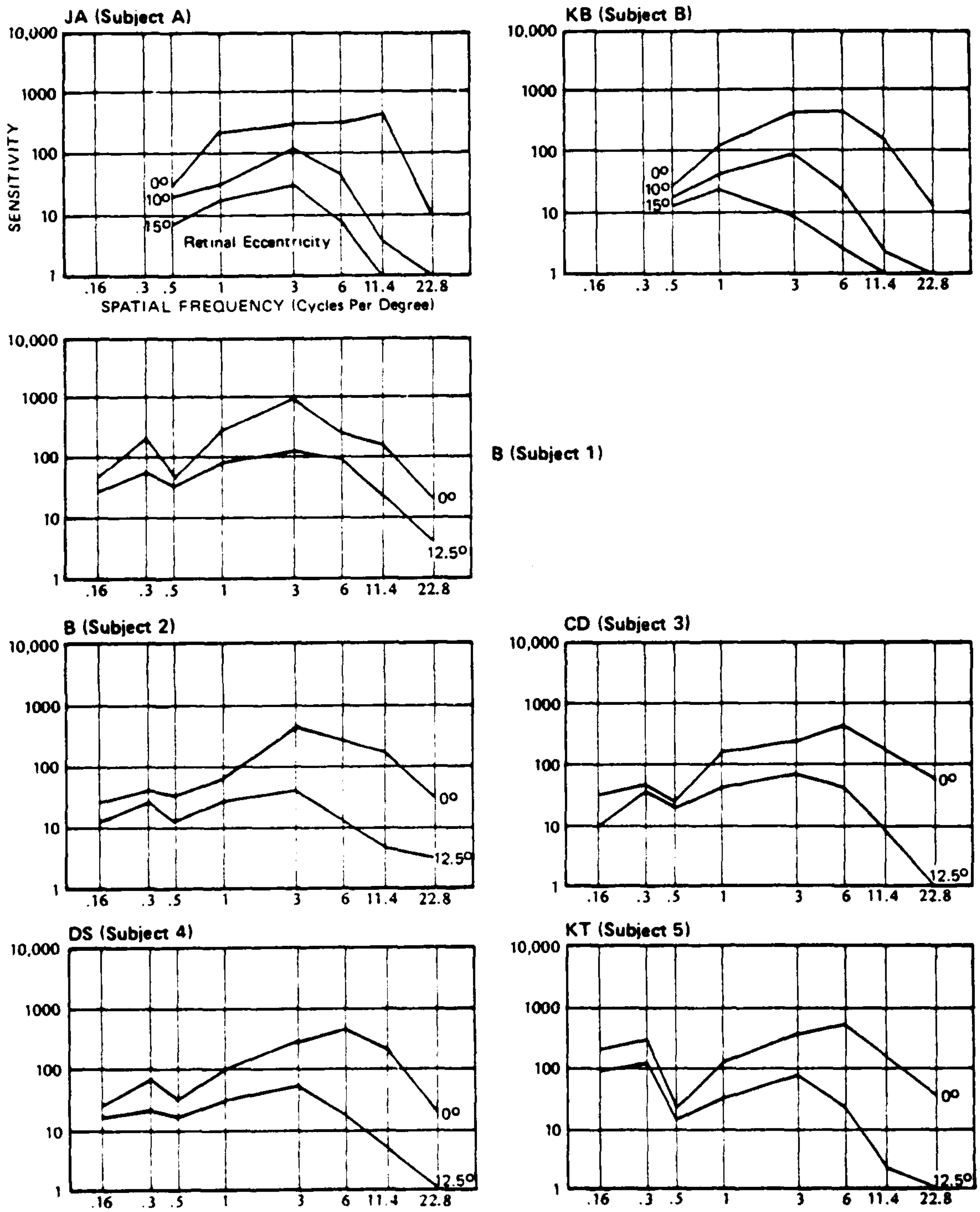

Figure B-8. Contrast Sensitivity Functions (in Log Threshold).

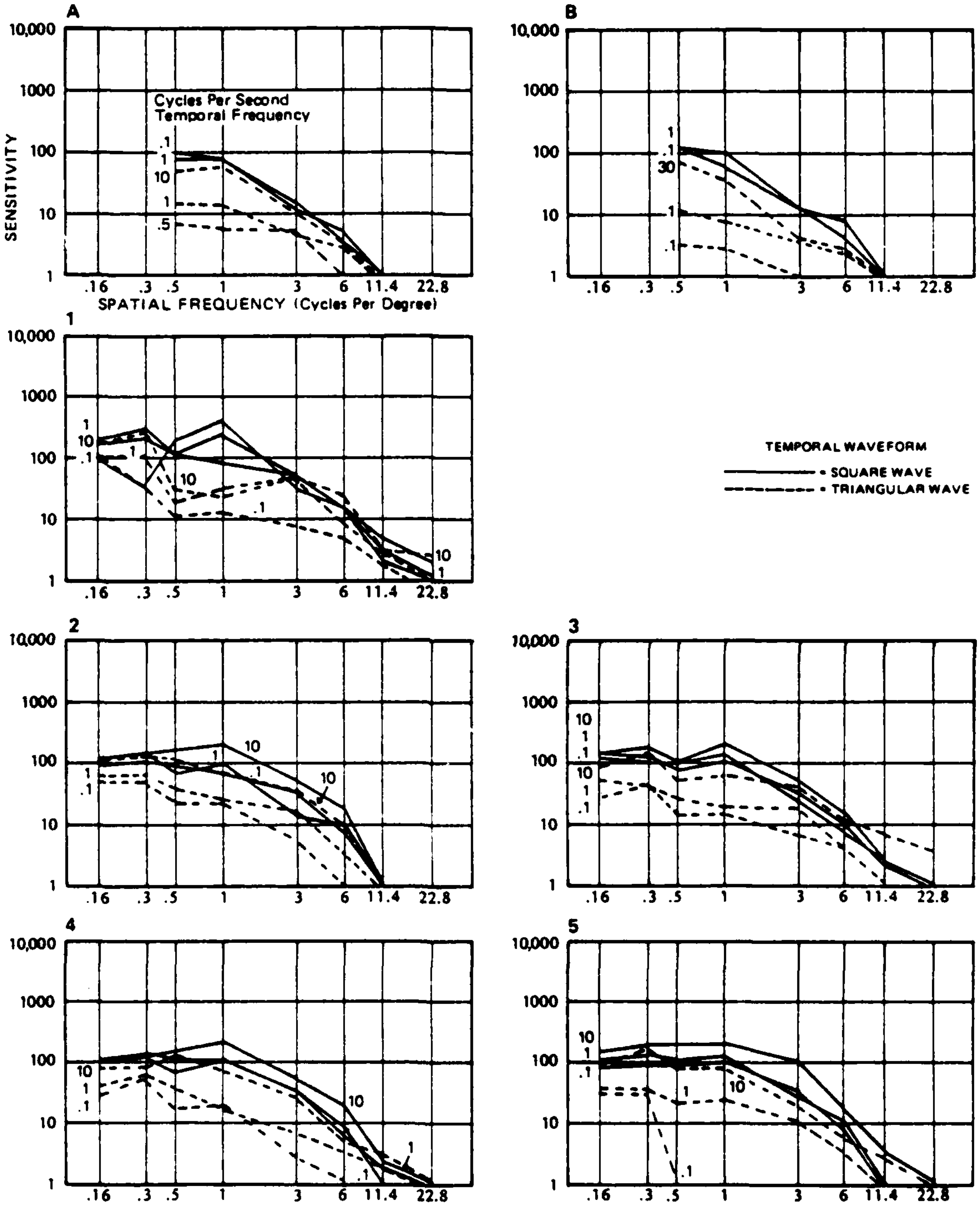

Figure B-9. Popping Threshold.

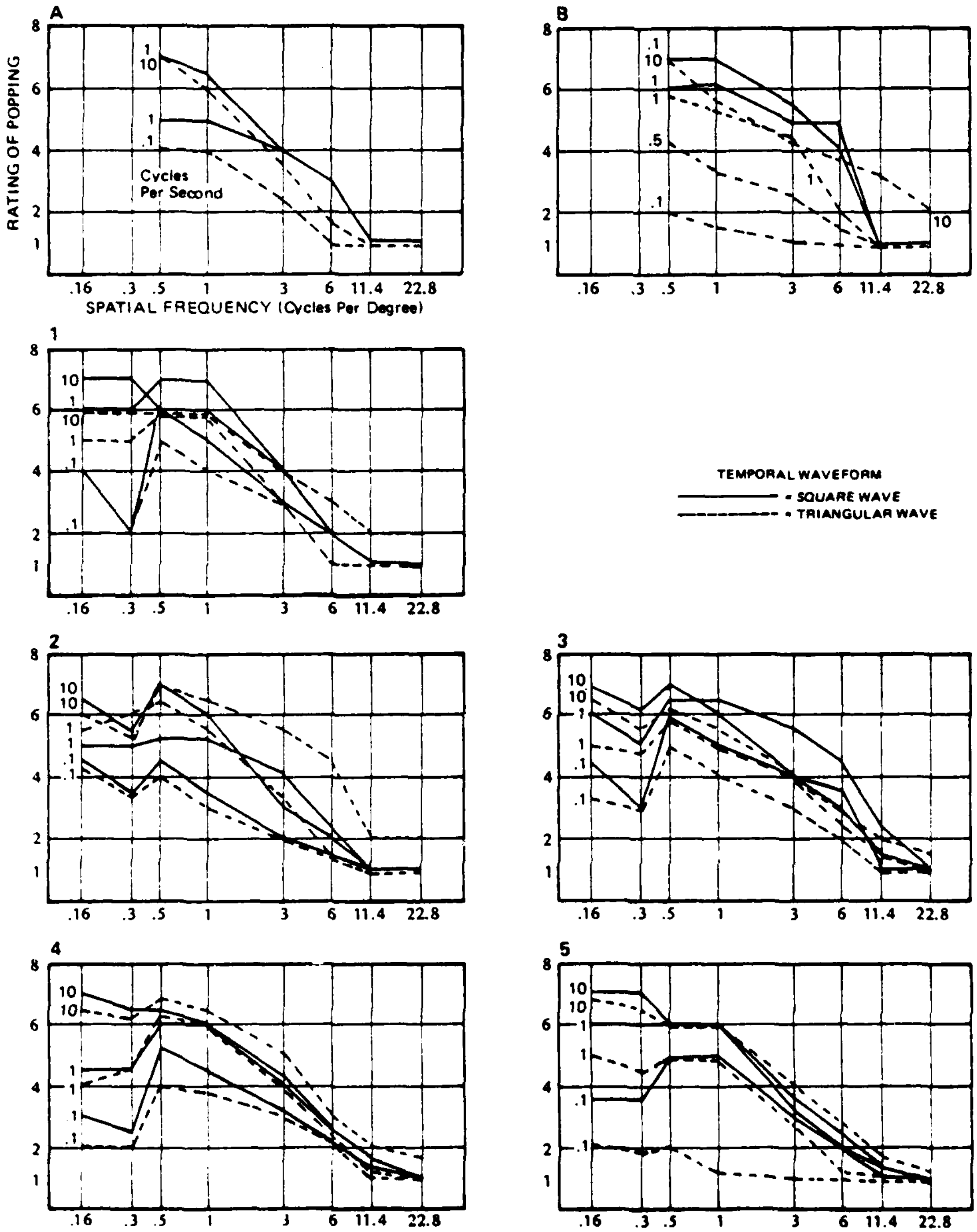

Figure B-10. Rating of Popping.

APPENDIX C

ADAPTATION

TABLE C-15. RAW DATA AND T-TEST SUMMARY

Condition	Spat. Freq. (cycle/ deg.)	Temp. Freq. (cycle/ sec.)	DJ	CD	BN	BR	KT	T-test p Value	Sign
1-pretest	.5	1	-1.14	-1.4	-1.45	-1.07	-1.26	.01 **	5 of 5
1-post-test	.5	1	- .85	- .909	-1.17	- .58	- .69		
2-pretest	.5	10	-1.74	-1.66	-2.12	-1.4	-1.82	.01 **	5 of 5
2-post-test	.5	10	-1.02	-1.13	-1.17	-1.01	-1.24		
3-pretest	3.	1	- .63	- .9	- .88	- .909	- .73		
3-adapt.	.5	1						ns	4 of 5
3-post-test	3.	1	- .75	- .53	- .82	- .51	- .5		
4-pretest	.5	1	-1.26	-1.02	-1.34	-1.06	-1.07		
4-adapt.	3.	1						ns	4 of 5
4-post-test	.5	1	-1.18	-1.15	-1.19	- .9	- .8		
5-pretest	.5	10	-1.41	-1.75	-1.75	-1.6	-1.97		
	.5	1						ns	3 of 5
5-post-test	.5	10	-1.4	-1.68	-1.69	-1.37	-1.82		
6-pretest	.5	1	-1.26	-1.18	-1.25	-1.28	-1.15		
6-adapt.	.5	10						ns	4 of 5
6-post-test	.5	1	-1.08	- .919	-1.46	- .65	- .949		

APPENDIX D

ATTENTION

TABLE D-16. ANOVA AND MARGINAL MEANS - ATTENTIONAL LOAD

ANOVA

Source of Variation	Sums of Squares	df	Mean Squares	F Ratio	p Value
Attentional Load	0.4485	1	0.4485	4.983	ns
Temporal Frequency	6.2059	1	6.2059	32.652	.005
Spatial Frequency	1.9641	2	0.982	12.139	.005
A * T	0.021	1	0.021	2.157	ns
A * S	0.0339	2	0.0169	1.434	ns
T * S	0.067	2	0.0335	2.409	ns
A * T * S	0.0131	2	0.0065	0.272	ns
A	0.5399	6	0.0899		
T	1.1403	6	0.19		
S	0.9707	12	0.0808		
A * T	0.0585	6	0.007		
A * S	0.1419	12	0.0118		
T * S	0.167	12	0.0139		
A * T * S	0.2894	12	0.0241		
TOTAL	13.6186	83			

Means (Log Threshold)

Attentional	
No Load	-1.50
Load	-1.35
Temporal Frequency	
1 cycle/sec	-1.15
10 cycle/sec	-1.70
Spatial Frequency	
.5 cycle/degree	-1.53
1. cycle/degree	-1.53
3. cycle/degree	-1.21

TABLE D-17. ATTENTIONAL LOAD RAW DATA

Summary Data - Attention

KB

T	S	No Load	Load
1	.5	-1.458	-1.393
	1.	-1.192	-1.158
	3.	- .608	- .672
10	.5	-2.072	-2.015
	1.	-1.028	-1.9
	3.	-1.338	-1.328

JA

T	S	No Load	Load
1	.5	-1.187	-1.065
	1	-1.373	-1.318
	3	-1.257	-1.387
10	.5	-1.885	-1.787
	1.	-1.867	-1.798
	3.	-1.695	-1.65

CD

T	S	No Load	Load
1	.5	-1.042	- .735
	1.	-1.075	-1.062
	3.	- .997	- .67
10	.5	-1.618	-1.712
	1.	-1.73	-1.557
	3.	-1.532	-1.273

BN

T	S	No Load	Load
1	.5	-2.257	-1.493
	1.	-1.683	-1.46
	3.	-1.58	-1.518
10	.5	-1.85	-1.797
	1.	-1.873	-1.653
	3.	-1.52	-1.458

BR

T	S	No Load	Load
1	.5	-1.325	- .697
	1.	-1.362	- .937
	3.	-1.217	- .583
10	.5	-1.857	-1.448
	1.	-1.853	-1.62
	3.	-1.495	- .967

KT

T	S	No Load	Load
1	.5	-1.048	-1.273
	1.	-1.093	-1.07
	3.	- .668	- .552
10	.5	-2.137	-1.85
	1.	-1.965	-1.977
	3.	-1.083	-1.61

DS

T	S	No Load	Load
1	.5	-1.345	-1.162
	1.	-1.292	-1.163
	3.	- .99	- .947
10	.5	-1.813	-1.642
	1.	-1.912	-1.827
	3.	-1.677	-1.527

KEY: T = Temporal Frequency
S = Spatial Frequency

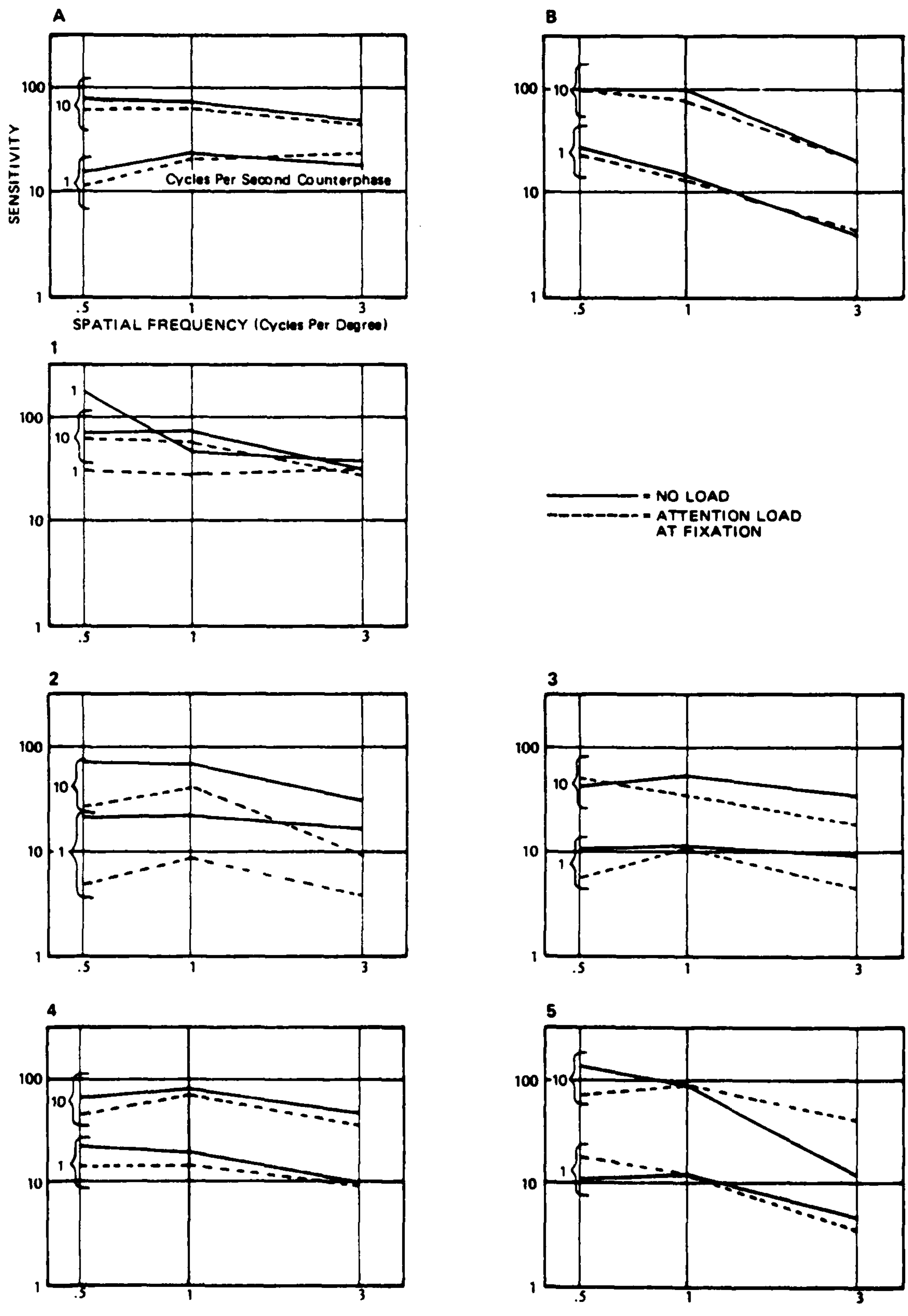

Figure D-11. Effect of Attention upon Popping Sensitivity (at 12.5° Eccentric.)

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Williams AFB, AZ 85224

Dr. Kenneth Boff 1
ARAMRL/HEA
WP AFB, Ohio 45433

CAPT James Goodson 1
Code L-32
Naval Aerospace Medical
Research Laboratory
Pensacola, FL 32512

Engineering Psychology 1
Group
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Mr. Edward M. Connelly 1
Performance Measurement Assoc.
410 Pine St., S. E. 300
Vienna, VA 22180

Mr. John O. Duffy 1
U. S. Army Test
and Eval. Command
Aberdeen Proving Ground
Maryland 21005

Dr. David C. Nagel 1
LM-239-3
NASA Ames Research Center
Moffett Field, CA 94035

Federal Aviation Admin 1
Technical Library
Bureau Research & Development
Washington, D C 20590

Commander 1
Naval Weapons Center
Human Factors Branch
Code (3194)
Attn: Mr. Ronald A. Erickson
China Lake, CA 93555

Mr. Robert Wright 1
USARI Field Unit
Ft. Rucker, AL 36362

LTCOL Jefferson Koonce 1
USAFA/DFBL
USAF Academy, CO 80840

Superintendent 1
Code 602
Human Factors Engineering
Division
Naval Air Development Center
Warminster, PA 18974

Dr. Will Bickley 1
USARI Field Unit
P. O. Box 476
Fort Rucker, AL 36362

CDR W. F. Moroney 1
Systems Engineering Test
Directorate (SY 70F)
Naval Air Test Center
Patuxent River, MD 20670

CDR, Soldier Support Center 1
ATTN: ATZI-NCR-SI (MAJ Wildrick)
Ft. Benjamin Harrison
Indiana 46216

Mr. Heinz Friedrich 1
Chief, Flight Simulation Branch
Dornier GmbH
Postfach 1426
D7990 Friedrichshafen FRG

Mr. Clarence A. Fry 1
U.S.Army Human Engineering Lab
Attn: DRXHE
Aberdeen Proving Ground
Maryland 21005

Dr. Richard F. Gabriel 1
Douglas Aircraft Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

Dr. Ralph Haber 1
AFHRL/OTR
Williams AFB, AZ 85224

Dr. Genevieve Haddad 1
AFOSR/NL
Bolling AFB, D C 20332

Dr. Edward R. Jones 1
Chief, Human Factors Engr.
McDonell Douglas Corp
St. Louis, MO 63166

Mr. Charles E. Kaul 1
7101 Galgate Drive
Springfield, VA 22153

Dr. William J. King 1
Ergonomics Associates, Inc.
P. O. Box 20987
Orlando, FL 32814

Dr. Herschel W. Leibowitz 1
Professor of Psychology
614 Bruce V. Moore Building
Pennsylvania State University
University Park, PA 16802

Chief, HEL Detachment 1
Attn: DRXHE-MI (Mr. Nichols)
U. S. Army Missile Command
Redstone Arsenal, AL 35898

Mr. William A. Breitmaier 1
Code 6022
Naval Air Development Center
Warminster, PA 18974

Dr. Clyde A. Brictson 1
Dunlap and Associates, Inc.
920 Kline St., Suite 203
La Jolla, CA 92037

Dr. W. Marvin Bunker 1
General Electric Corp
P. O. Box 2500
Daytona Beach, FL 32015

Dr. Paul W. Caro 1
Seville Research Corp
400 Plaza Bldg.
Pensacola, FL 32505

Mr. Vernon E. Carter 1
Northrop Corp., Aircraft Div.
3901 W. Broadway
Hawthorne, CA 90250

Dr. Eric Haseltine 1
Hughes Aircraft Corp
Building R-1
M/S C-320
Los Angeles, CA 90009

Dr. Robert T. Hennessy 1
Committee on Human Factors
National Research Council
2101 Constitution Ave.
Washington, D C 20418

Dr. William M. Hinton, Jr. 1
Allen Corporation
3751 Maguire Blvd., Suite 270
Orlando, FL 32803

Mr. James McGuinness 1
Person-System Integration
3012 Duke Street
Alexandria, VA 22314

Dr. Melvin D. Montemerlo 1
RTE-6
NASA Headquarters
Washington, D C 20546

Dr. Frederick A. Muckler 1
Essex Corporation
741 Lakefield Rd., Suite B
Westlake Village, CA 91361

Dr. Kent A. Stevens 1
Department of Computer and Information Science
University of Oregon
Eugene, OR 97403

Dr. Paul E. Van Hemel 1
Allen Corporation of America
401 Wythe Street
Alexandria, VA 22314

Mr. Donald Vreuls 1
Vreuls Research Corporation
68 Long Court, Suite E
Thousand Oaks, CA 91360

Mr. Lee Wooldridge 1
Vreuls Research Corporation
6568 University Boulevard
Orlando, FL 32807

Dr. Laurence Young 1
Dept. of Aeronautics
Massachusetts Inst. of Tech.
77 Massachusetts Ave.
Cambridge, MA 02139

Mr. J. Thel Hooks, Jr. 1
Dunlap and Associates
920 Kline St., Suite 203
La Jolla, CA 92037

Ms. Joyce Iavecchia 1
Naval Air Development Center
Code 6022
Warminster, PA 18974

Dr. Richard S. Jensen 1
Department of Aviation
Ohio State University
Box 3022
Columbus, OH 43210

Mr. Henry R. Jex 1
Systems Technology Inc.
13766 Hawthorne Blvd
Hawthorne, CA 90250

CDR, Naval Air Force 1
U. S. Atlantic Fleet
Attn: LCDR Robert Day
Norfolk, VA 23511

Dr. Wallace W. Prophet 1
Seville Research Corp
400 Plaza Bldg.
Pace Blvd. at Fairfield Dr
Pensacola, FL 32505

Professor Stanley N. Roscoe 1
Department of Psychology
New Mexico State University
Box 5095
Las Cruces, NM 88003

R. F. Schiffler 1
ASD/ENECH
Wright-Patterson AFB
Ohio 45433

Mr. Moses Aronson 1
3705 Wilder Lane
Orlando, FL 32804

Dr. Kevin Berbaum 1
P.O. Box 435
West Branch, IO 52358

Dr. Edward A. Stark 1
Link Division
The Singer Company
Binghamton, NY 13902

Mr. John B. Sinacori 1
P. O. Box 1043
Hollister, CA 95023

Dr. Harry L. Synder 1
VPI&SU, Dept. of Indus. Engr. and Operations Research
130 Whittemore Hall
Blacksburg, VA 24061