Display Spatial Luminance Nonuniformities: Effects on Operator Performance and Perception

by

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(ABSTRACT)

This dissertation examined the effects of display spatial luminance nonuniformities on operator performance and perception. The objectives of this research were to develop definitions of nonuniformity, develop accurate measurement techniques, determine acceptable levels of nonuniformities, and to develop a predictive model based on user performance data.

Nonuniformities were described in terms of spatial frequency, amplitude, display luminance, gradient shape, and number of dimensions. Performance measures included a visual random search task and a subjective measure to determine users' perceptions of the nonuniformities. Results showed that users were able to perform the search task in the presence of appreciable nonuniformities. It was concluded that current published recommendations for acceptable levels of nonuniformities are adequately specified. Results from the subjective task showed that users were sensitive to the presence of nonuniformities in terms of their perceptions of uniformity.

Specifically, results showed that as spatial frequency increased, perceived uniformity ratings increased. That is, users rated nonuniformities to be less noticeable. As amplitude and display luminance increased, the users' ratings of perceived uniformity decreased; that is, they rated the display as being farther from a uniform field. There were no differences in impressions between a sine and triangle gradient shape, while a square gradient shape resulted in lower ratings of perceived uniformity. Few differences were attributed to the dimension (1-D versus 2-D) of the nonuniformity and results were inconclusive because dimension was confounded with the display luminance.

Nonuniformities were analyzed using Fourier techniques to determine the amplitudes of the coefficients for each nonuniformity pattern. These physical descriptors were used to develop models to predict users' perceptions of the nonuniformities. A few models yielded good fits of the subjective data. It was concluded that the method for describing and measuring nonuniformities was successful. Also, the results of this research were in strong concurrence with previous research in the area of spatial vision.

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INTRODUCTION

In visual displays, systematic changes in luminance or color are used to present picture details and gray scale rendition. Display luminance uniformity refers to the ability of a display to present a uniform luminance across the display screen and is important for the appearance of a continuous picture. Display nonuniformity refers to unintended changes in luminance or color on the display that may result in image degradation. From a marketing standpoint, displays which manifest obvious nonuniformities may be esthetically displeasing to the customer. From a performance standpoint, nonuniformities may directly affect task performance.

Research investigating the effects of display nonuniformities is very limited. Farrell and Booth (1984) categorized cathode ray tube (CRT) nonuniformities into systematic and nonsystematic changes in screen luminance. Two examples of systematic nonuniformities are phosphor burn and the luminance difference from the center to the edge of a CRT screen. Examples of nonsystematic nonuniformities were described as blemishes and categorized into four types:

Dynamic - blemishes caused by writing or erasing functions.

Static - blemishes not caused by writing or erasing functions.

Light blemishes -blemishes lighter than the background.

Dark blemishes - blemishes darker than the background.

Farrell and Booth (1984) gave descriptive examples of different blemishes such as pattern burns, raster burns, and blue edges (the area near the edge of the screen appears more blue than the center).

It is not feasible to list and describe all of the different types of nonuniformities that may exist on each of the different display technologies. Goede (1978, cited by Snyder, 1980) proposed categorizing nonuniformities into three types:

Large area - luminance or color gradients from one area on the screen to another, such as edge-to-edge or center-to-center. An example is the center-to-edge luminance difference commonly found on CRTs. Because CRTs have curved screens, the beam strikes the phosphor at oblique angles, which is the primary cause of the luminance difference (Farrell and Booth, 1984).

Small area - luminance or color changes from element to element. Examples of this type of nonuniformity are blemishes, dirt specks, and element failures.

Edge discontinuity - luminance or color gradients extending across a boundary resulting in the impressions of edges or discontinuous figures. For example, some flat panel displays are manufactured such that several small displays are matrixed together to form one large screen display. The boundaries where these smaller displays are joined may result in impressions of edges. Another example is line failures common to some matrix-addressed displays.

While these categories are somewhat useful, they are limited. The definition of "large" or "small" area is not adequately specified. The extent and type of luminance gradient are also not defined. The nonuniformities discussed above refer to luminance or color changes that are inherent in the display technology. Another example of nonuniformities is Moire patterns that may appear with the introduction of mesh glare filters placed over the display. Also, a digitized image may result in nonuniform outputs because of the sampling rate used. These types of nonuniformities do not fall neatly into the above categories.

Problem Statement

Electronic displays are used for many critical tasks such as photointerpretation, sophisticated cartographic and symbolic representation for many military systems, computer-aided design and computer-aided manufacturing (CAD/CAM), and other graphic applications. Displaying an accurate continuous image is often critical to task performance. Although operators may be able to perform such tasks with displays that exhibit nonuniformities, we do not know how the nonuniformities may affect performance. Accurate measurement techniques for describing spatial nonuniformities and recommendations for acceptable levels are needed.

It is possible that the effects of luminance nonuniformity will vary with the type of task and the type of information displayed. Performing the numerous experiments to investigate empirically the effects of all possible combinations is not feasible. Thus, a more general predictive metric which relates the nonuniformity to operator performance is recommended. The objectives of this research are to measure and define nonuniformity and to develop a predictive metric based on user performance data.

BACKGROUND

Detecting Luminance Gradients

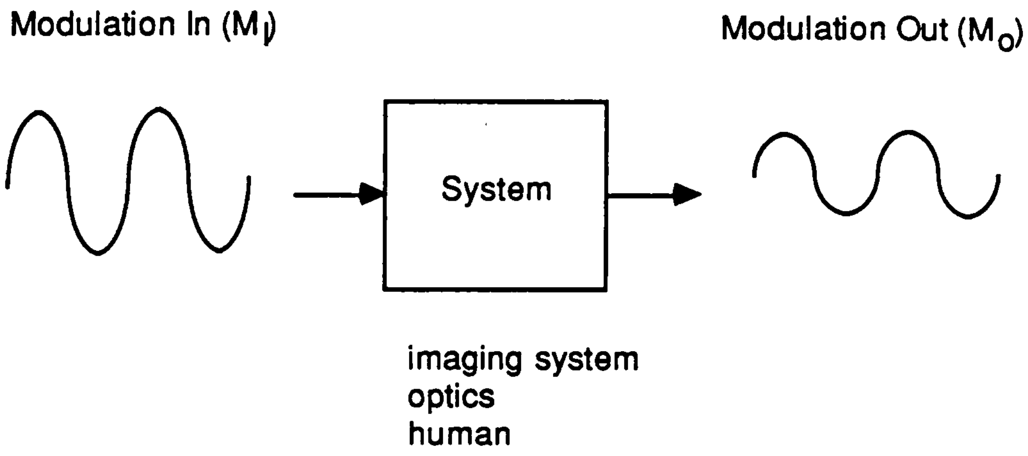
Research which deals with detecting visual suprathreshold luminance gradients is limited, as most of the literature deals with threshold measurement. Knowledge of the threshold levels can give an indication of what the observer can detect, although performance is unlikely to be affected by luminance gradients at or near threshold.

Brown and Mueller (1965) reviewed the vision literature dealing with the ability to detect threshold changes in luminance. In these experiments, an adapting luminance (L) was presented to the observer and the luminance change (ΔL) required by the observer to detect the change was determined. Many different variables were manipulated and found to influence the ability to detect luminance changes. Examples include task type and stimulus parameters such as size, duration, and shape. Even with these data, it is difficult to predict quantitatively absolute detection thresholds because they vary with all these parameters and their interactions.

Another approach to this topic has been to apply the concepts of linear systems analysis and the mathematics of Fourier transforms. With linear systems analysis it is possible to determine the extent to which any component or system of components can transmit a signal. During transmission some of the signal is lost due to limitations of the system (e.g., limited bandwidth) as illustrated in Figure 1. Modulation is defined as:

$$\text{Modulation (M)} = \frac{(\text{Lmax} - \text{Lmin})}{(\text{Lmax} + \text{Lmin})}, \qquad (1)$$

where Lmax is the maximum luminance and Lmin is the minimum luminance. The modulation



Modulation Transfer Factor

$$T(\omega) = \frac{M_O(\omega)}{M_I(\omega)}$$

where $T(\omega)$ is the modulation transfer factor at spatial frequency ω, and $M_O(\omega)$ and $M_I(\omega)$ are the output and input modulations, respectively.

Figure 1. Transmission of a signal through a linear system.

transfer factor is the ratio of the modulation out of the system to the modulation into the system as defined in equation 2.

$$T(\omega) = \frac{M_O(\omega)}{M_I(\omega)}, \tag{2}$$

If the modulation transfer factor values at each spatial frequency are connected, a continuous function is formed, the modulation transfer function or MTF. An example of an MTF is illustrated in Figure 2. The modulation transfer function or MTF is a measure of the fidelity in a system. The measurement is made for a sine wave of known amplitude or modulation. The loss of output modulation generally increases with increasing frequency of the sine-wave input.

These concepts have been applied to the visual system. An observer is presented with a known sine-wave pattern that is varied in spatial frequency and he adjusts the luminance contrast (modulation) of the grating to his visual threshold. When the results are plotted as a function of spatial frequency the function is termed the contrast threshold function or CTF. Figure 3 illustrates CTFs for different levels of display luminance (van Meeteren, Vos, and Bongaard, 1968, as cited by Snyder, 1980). At higher levels of display luminance the eye is most sensitive to frequencies between 3 and 5 cycles per degree of visual angle. Higher modulations are required as the spatial frequency decreases or increases. As display luminance is decreased, higher modulations are required for threshold detection and peak sensitivity shifts to lower frequencies.

Fourier analysis states that any repetitive waveform can be analyzed into its sine-wave components with each component frequency having a specific amplitude and phase relationship, such that they can be recombined into the original image. The

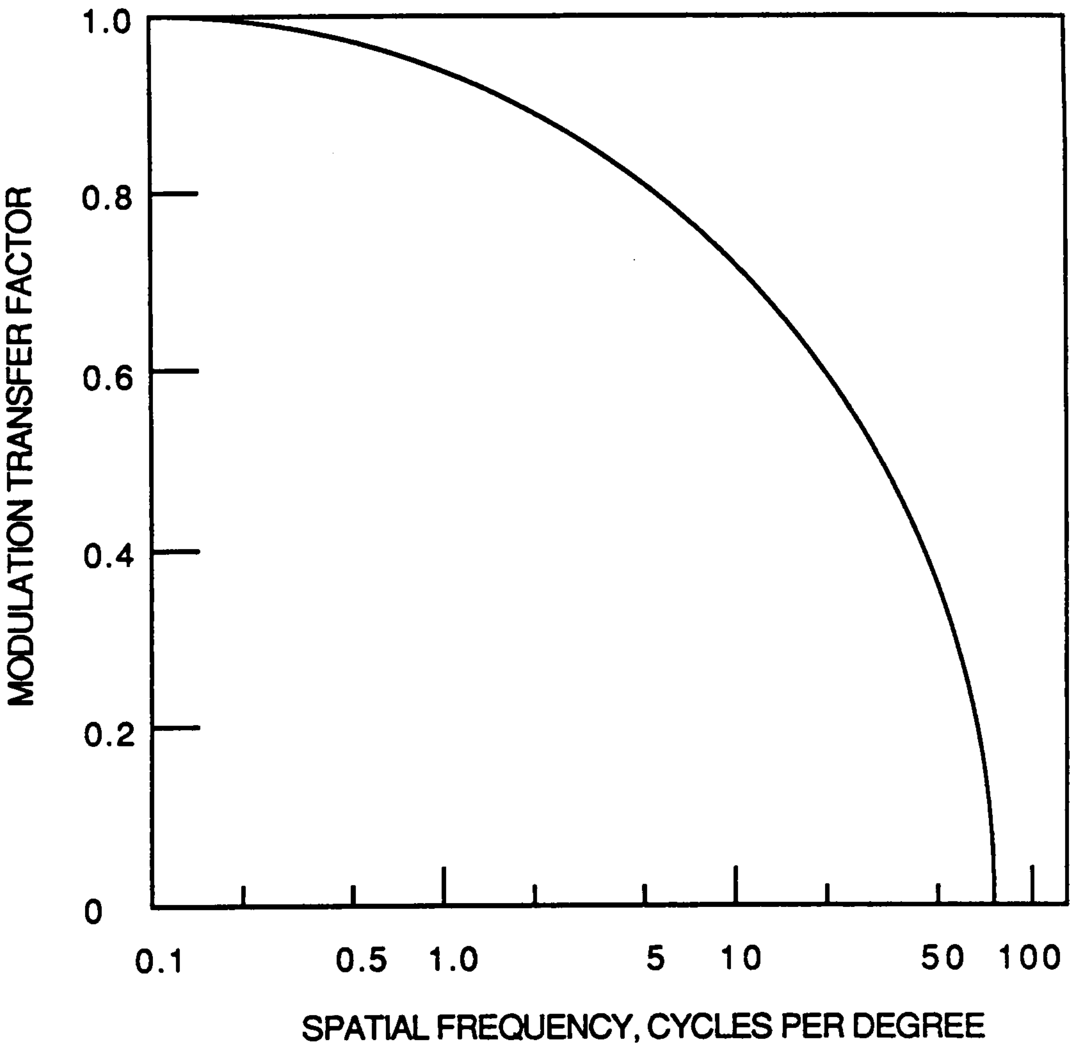


Figure 2. The modulation transfer function (MTF).

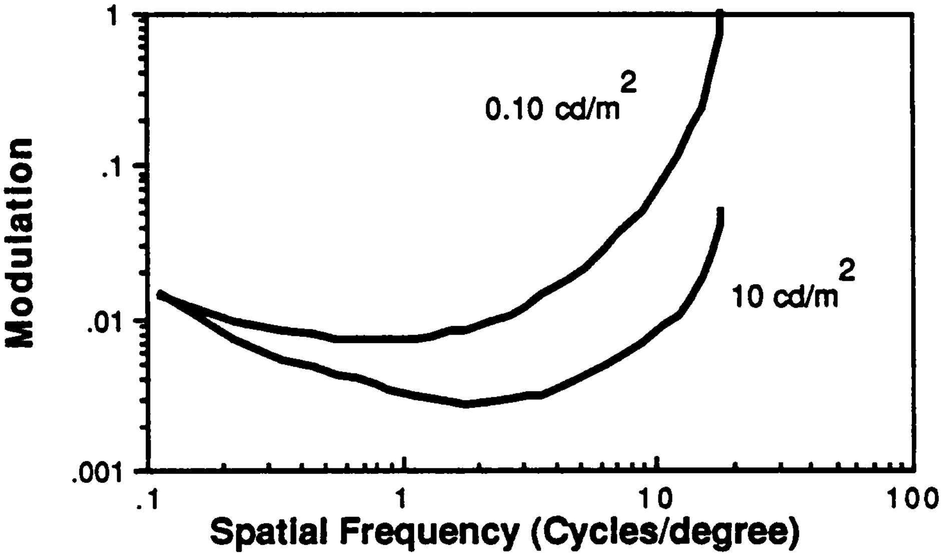


Figure 3. The contrast sensitivity function as a function of display luminance from van Meeteren et al., 1968, adapted from Snyder, 1980).

component frequencies of the image can be compared to the CTF of the visual system to determine whether the frequencies can be detected by the visual system. For example, if high frequency information is critical to performance then it is important that the high frequency information be preserved. A Fourier analysis of the displayed information can be used to determine if the high frequency information is detectable to the observer. If the amplitudes exceed the observer's threshold, then the information is detectable.

Figure 4 illustrates an example of this concept. The top part of the figure illustrates the first two components of a square wave. The second figure is a spectrum which shows the sine wave content of the image. The third figure is the contrast sensitivity function (CSF) of the visual system, which is the inverse of the CTF. The eye attenuates the lowest frequency component. The last part of the figure is the spectrum of the image as seen by the eye.

De Palma and Lowry (1962) measured the threshold response for sine- and square-wave gratings at different spatial frequencies. Their results indicated that for both sine and square waves the visual system was most sensitive between 3 and 5 cycles per degree. They also found that below 6 cycles per degree the square wave required less modulation for detection than did the sine wave.

This result can be predicted using Fourier techniques. A square wave can be produced by adding sine waves starting with a sine wave that has the same fundamental frequency as the square wave and adding additional sine waves with frequencies that are odd multiples (3X, 5X, 7X ...) of the fundamental frequency with amplitudes that are 1/3, 1/5, 1/7 ... of the fundamental (Cornsweet, 1970). When the Fourier components of a square wave and a sine wave that have the same fundamental frequency and peak-to-peak amplitudes are compared, the amplitude of the fundamental is $4/\pi$ (or 1.273)

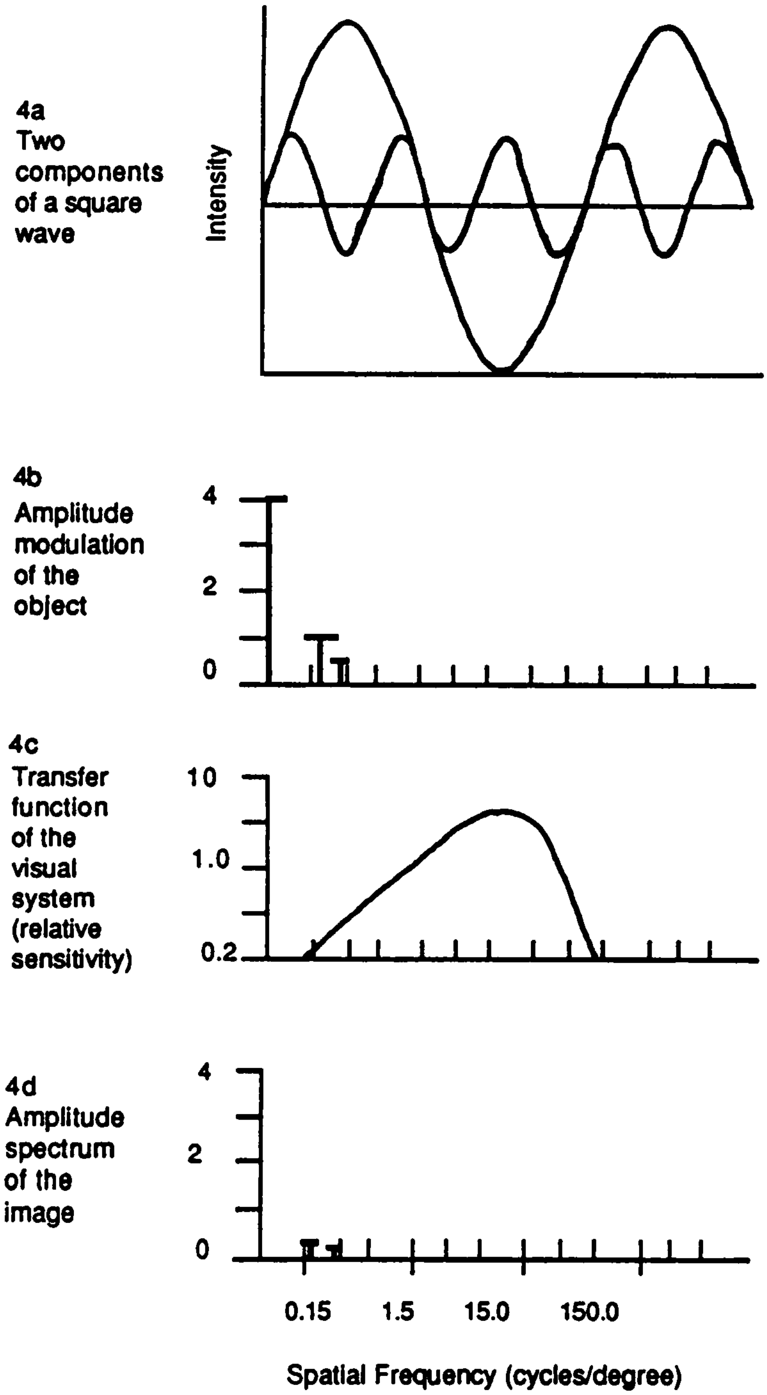


Figure 4. Fourier analysis technique for predicting visual detection of a square wave pattern (after Cornsweet, 1970.

higher for the square wave than for the sine wave; therefore, the square wave requires less modulation to detect. The higher order harmonics contribute to detection also, but only up to a point. The sensitivity of the eye decreases beyond 5 cycles/degree. If the higher order harmonics are beyond 5 cycles/degree they will contribute less to detection (Snyder, 1980). This relationship was demonstrated by De Palma and Lowry (1962).

Results from studies on contrast sensitivity indicate that the spatial frequency of a nonuniformity (luminance gradient) and the type of periodic pattern or waveform of the nonuniformity will influence how it is perceived. A low spatial frequency or very gradual change in luminance will probably go undetected by the observer. However, it will depend upon the pattern underlying the gradient (e.g., square, sinusoidal, linear, etc.). Therefore, rather than defining nonuniformity in terms of large area or small area, spatial frequency is more descriptive and more likely to be generalized validly to a variety of display conditions.

Nonuniformity Experiments

Low frequency luminance nonuniformities. McCann, Savoy, Hall, and Scarpetti (1974) investigated continuous linear luminance gradients and sinusoidal periodic patterns. Contrast (defined as (Lmax-Lmin)/Lmax) and retinal gradient were the independent variables. Retinal gradient referred to the rate of change of flux on the retina and was defined as (contrast)/(retinal angle between Lmax and Lmin).

In the first experiment luminance was varied linearly in one direction across a square target 10.2 cm^2. The target was constructed using photographic print paper. Five contrast levels were used. Targets were placed in an illumination box and uniformly illuminated from within. All targets were scanned using a telephotometer and the center luminance of each target was 527.6 cd/m^2. The targets subtended 4.8 degrees of visual angle and were presented in four orientations, with the maximum luminance on top, bottom, left, or right (i.e., maximum luminance to minimum luminance). Observers were asked to identify the dimmest edge and correct responses were recorded.

In order to determine the effects of retinal gradient, the targets were also viewed at distances which yielded a constant retinal gradient. Table 1 summarizes the target contrasts and results. The percent correct was greatest for the highest luminance contrast condition (i.e., the steepest slope) and progressively lower as target contrast decreased. When retinal gradient was kept constant results were very similar, indicating that visibility was not a function of retinal gradient. If a 50-percent detection accuracy is defined as the threshold, a contrast between 0.12 and 0.17 was required. A contrast of 0.33 resulted in 93 percent correct detection rates.

In the second experiment sinusoidal luminance gratings were used and contrast was kept constant at 0.10. The gratings varied in spatial frequency between 0.5 and 2.8 cycles/degree as indicated in Table 2. Targets were presented in an octagon so that four orientations were possible. Observers were asked to determine the four orientations of the gratings. The results (see Table 2) are similar to other experiments dealing with sinusoidal gratings. As the spatial frequency increased, the visibility increased monotonically. At 2.8 cycles/degree the subjects responded correctly 100 percent of the time. At the lowest spatial frequency (0.5 cycle/degree) correct responses were at chance levels. Retinal gradient again was not a factor in determining visibility.

High frequency luminance nonuniformities. Limited research can be found with regard to high frequency luminance gradients or "small area" nonuniformity, or changes in luminance or color at the elemental or pixel level. Such nonuniformities may include

TABLE 1: Contrast Levels and Percent of Correct Responses for Linear Gradient Targets (from McCann et al.,1973).

Target	Contrast	% Correct viewed at 122 cm	Viewing distance for retinal gradient of 0.12	%Correct at a constant retinal
A	0.08	41	489	48
B	0.12	47	222	55
C	0.17	68	234	58
D	0.23	80	180	77
E	0.33	93	122	93

TABLE 2: Percent of Correct Responses for Detecting Sinusoidal Targets (from McCann et al., 1973).

Target frequency (c/deg)	% Correct viewed at 122 cm	Viewing distance (cm) for retinal gradient of 0.12	% Correct at a constant retinal
0.5	22	749	19
0.7	30	472	28
1.0	60	368	75
1.2	70	274	75
1.7	86	221	86
2.0	95	196	100
2.8	100	122	100

blemishes, dirt on the screen, or a change in luminance of the pixel. (This definition does not include the luminance change with respect to the element size.) The acceptable level will also vary with the number of nonuniformities on the screen.

An image can be stored in a computer electronically in digital form. A continuous tone image is sampled and quantized into different luminance levels or bits. These bit values are converted to analog values and sent to the display. A computer with the capability of storing 8 bits has 256 intensity levels (2^8) available that can be displayed on compatible display hardware. If the differences between these levels are small enough and there are enough levels, the luminance gradations will appear continuous. Some displays are only capable of displaying one bit of intensity information (on or off), such as the typical AC plasma panel; therefore, only two intensity levels can be displayed which may not be enough to present picture details which require fine luminance gradations without using techniques such as spatial or temporal dithering.

Emissive displays may exhibit luminance variations in pixels such that the luminance level is below or above the intended level. In the case of the plasma panel, the display may fail by having a pixel remain on or off irrespective of the intended state. Other matrix-addressed or cell-addressed displays may also have these types of failures. Effects of display failures have been investigated and the results are relevant to this topic.

Riley and Barbato (1978) evaluated the effects of discrete element degradation on the legibility of 5 x 7 dot-matrix fonts, including ASCII, Lincoln-MITRE, Huddleston, Ellis, and NAMEL fonts. Importance values were assigned to each dot which composed a character. Importance values were assigned as a function of the amount of degradation the character would suffer if the dot was removed. Each character was then degraded by the addition, removal, or both addition and removal of dots. Subjects performed a character identification task. The removal, addition, of simultaneous removal and addition of dots did not differentially affect character identification. There were also no differences among fonts. It should be noted that this study *systematically* removed or added dots and that display failures are typically random.

Abramson and Snyder (1984) investigated element failures on an AC plasma panel display to determine effects on operator reading performance. Two between-subject variables, font (Lincoln-MITRE, Huddleston, and a font from an HP2621A terminal), and case (mixed or upper) were investigated along with within-subject variables of failure type (vertical or horizontal line failures, cell failures), failure mode (failed on or off), and percent failure (0, 2, 4, 8, 12, 20). Failures were placed randomly on a screen with a 1024 x 1024 active area. The task was a Tinker speed of reading test. Response time and the frequency of correct, incorrect, and null responses were recorded.

As the percentage of cell failures increased from 0 to 20 percent, response time increased. This effect was most dramatic for mixed case text. ON cell failures resulted in significantly slower response times than OFF cell failures. For ON cell failures the mixed case was significantly slower than upper case. The Huddleston font resulted in the fastest response times regardless of whether the failure was ON or OFF.

In terms of response frequency, as the percent failure increased the proportion of incorrect responses increased. Above 8% the proportion of null responses increased. The authors concluded that failures below 2% would not result in reading performance degradation. This conclusion may not hold for more complex task situations in which reading is not the primary task.

Further investigations into the effects of display failures were conducted by Decker, Dye, Kurokawa, and Lloyd (1988) and Lloyd, Decker, Kurokawa, and Snyder (1988). Results from both studies supported results obtained by Abramson and Snyder (1984). In addition, it was found that display failures were more detrimental when performing a random search task then when performing a Tinker reading task. With a percent failure of 4%, search performance was degraded 28% and reading performance was degraded 4% from a no-failure condition. For search type-tasks, ON cell failures above 1% should be avoided.

The research described above revealed that display failures which cause high frequency nonuniformities across the screen will influence performance; however, acceptable levels and quantitative predictive metrics for describing high frequency nonuniformities are difficult to establish. The spatial frequency of the nonuniformity was not varied, nor was the degree of luminance change (or amplitude of the nonuniformity). Further research is still needed.

Current Levels of Nonuniformity on Displays

Prior to describing and measuring the effects of display nonuniformities it is necessary to determine current levels of display nonuniformities in the market. Unfortunately, without an accurate and standard definition of the term it is difficult to determine current levels.

Several sources have attempted to address the effects of low frequency luminance changes on displays. Klaiber (1966) measured physical and optical properties of projection screens. Although no data were presented he stated, "Preliminary studies in our laboratory indicate that the luminance gradient across an empty field will be tolerable (when information is later displayed) if the luminance at the field edges is one-third of that at the center. These results depend greatly on the shape of the luminance gradient; our study is based on a linear gradient."

Tannas (1985) stated that for television displays center-to-edge gradients of two-to-one go "generally unnoticed." He did not indicate the size of the display; however, he did indicate that the acceptable levels will depend on the end use of the display. Unfortunately no data were presented regarding typical levels of nonuniformity in the current market.

Vogel (1974) measured average luminance levels from the center to the edge of two types of color televisions. He found gradients of 53 to 63 percent from center to edge.

Pigion, Decker, Hunter, and Snyder (1986) made center and four corner average luminance measurements on a gray scale Sun 2/160 19-inch CRT monitor. The corner measurements were made one inch from the corners of the screen. These measurements were made with all pixels at 0 and full (255) bit levels. The brightness adjustment was varied until the center luminance level reached 80 cd/m^2. All measurements were then made without adjusting the brightness control. Results are presented in Table 3. At 255 bits, the right corners were approximately 6.4 percent greater in luminance than the center, while the left corners were approximately 6.6 percent lower than the center luminance.

TABLE 3: Center and Corner Luminance Levels for a Sun 2/160 Gray Scale Monitor (from Pigion et al., 1986).

	Luminance at 0 bits (cd/m^2)	Luminance at 255 bits (cd/m^2)
center	0.2	80.6
top left	0.3	75.2
top right	0.4	87.9
bottom left	0.3	75.4
bottom right	0.4	83.7

The research and recommendations seem to indicate that luminance gradients from center to edge on current CRTs including televisions can be as high as 60 percent, although some systems are within 10 percent.

The American National Standard for Human Factors Engineering of Visual Display Terminal Workstations (1988)recommends that the luminance variation from the center to the edge of the active display area should vary no more than 50% of that of the center luminance. In reference to high frequency spatial luminance nonuniformities, the standard recommends that unintended luminance variations shall not vary by more than 50% within an area the size of half a degree of arc, at any position on the screen. (This value is calculated based on the display design viewing distance.) This last recommendation ensures that if a 50% luminance change does occur, it will not occur sharply creating the impression of an edge or dark spot. Validation of this standard is still needed.

Background Summary and Objectives

It is obvious that quantitative research is lacking to describe the effects of spatial luminance nonuniformities on human performance. Validation of current recommendations is needed. The objective of this research is to define nonuniformities in a manner which would allow systematic measurement, and to determine the effects of nonuniformities on human performance.

Underlying this investigation is the concept of the visual system as a Fourier analyzer in the spatial domain. The techniques of linear systems analysis and Fourier analysis are powerful analytical tools which can provide a quantitative measurement framework for describing nonuniformities. Also, a large body of literature in the areas of vision and visual display systems postulates a spatial frequency model for describing human visual responses. Describing nonuniformities in spatial frequencies enables comparison of results with previous research.

As previously discussed, visual detection thresholds vary as a function of spatial frequency, modulation, and the shape of the gradient (e.g., sine wave versus square wave). Therefore, to characterize nonuniformities, these variables will be included in the investigation. Describing nonuniformities in terms of spatial frequency allows nonuniformity to be described as a continuous variable, avoiding the discrete arbitrary definitions of large and small area.

In addition to the above variables, visual detection thresholds have also been found to vary as a function of the display luminance (van Meeteren et al., 1968). Because display luminance is a parameter that display users may adjust, it is important to include this variable in the investigation. For example, older users or observers who are viewing under high glare conditions may increase the display luminance.

Nonuniformities may vary in two dimensions on the screen; therefore, the effects of one- and two-dimensional nonuniformities should also be included in the investigation. Carlson, Cohen, and Gorog (1976) determined threshold responses for both 1-D and 2-D sine waves and found no significant difference in thresholds between the two patterns. However, the authors only reported results for one trained subject. The stimuli were presented on a CRT which would be limited in the high frequency ranges as a function of it's MTF. The limitations of the display were not discussed by the authors.

Describing nonuniformities in terms of spatial frequency, modulation, and gradient shape allows for physical measurement of the nonuniformities using photometric techniques. Physical measures of the nonuniformities can then be correlated with human performance. This technique is used in this investigation.

METHOD

Experimental Design

The experimental design was a 7 x 6 x 3 x 3 x 2 complete factorial and is shown in Figure 5. Seven levels of spatial frequency (F) were evaluated: 4, 8, 16, 32, 64, 128, and 256 cycles per display width (c/dw). The 256 c/dw condition consisted of waveforms of 2 pixels on and 2 pixels off. The waveform generators were bandwidth limited beyond this spatial frequency. The lower frequency value of 4 c/dw was selected based on research by Hoekstra, van der Goot, van den Brink, and Bilsen (1974), who found that when spatial frequency was held constant, the number of cycles presented in the grating affected threshold modulations. The critical number of cycles varied as a function of luminance. For the range of mean display luminance values of interest in this study, the critical number of cycles is approximately four. The figure also includes the frequency values in units of cycles/degree of visual angle (c/deg).

The six levels of amplitude (A) in peak-to-peak voltage were 0, 6, 10, 14, 20, and 24 mv. The A-0 condition was included as a baseline condition. That is, nonuniformities were not present. The three levels of display luminance (DL) were DL-1 = 0.003, DL-2 = 0.016, and DL-3 = 0.10 candela per square meter (cd/m^2). Display luminance refers to the mean luminance level of the nonuniformity and may also be considered as a voltage or luminance DC offset. Three gradient shapes (G) were investigated: square (SQ), triangular (TRI), and sine (SINE). The variable dimension (DIM) included one-dimensional (1-D) and two-dimensional (2-D) nonuniformities. The 1-D nonuniformities were in the vertical direction only. The 2-D condition consisted of horizontal and vertical nonuniformities summed together.

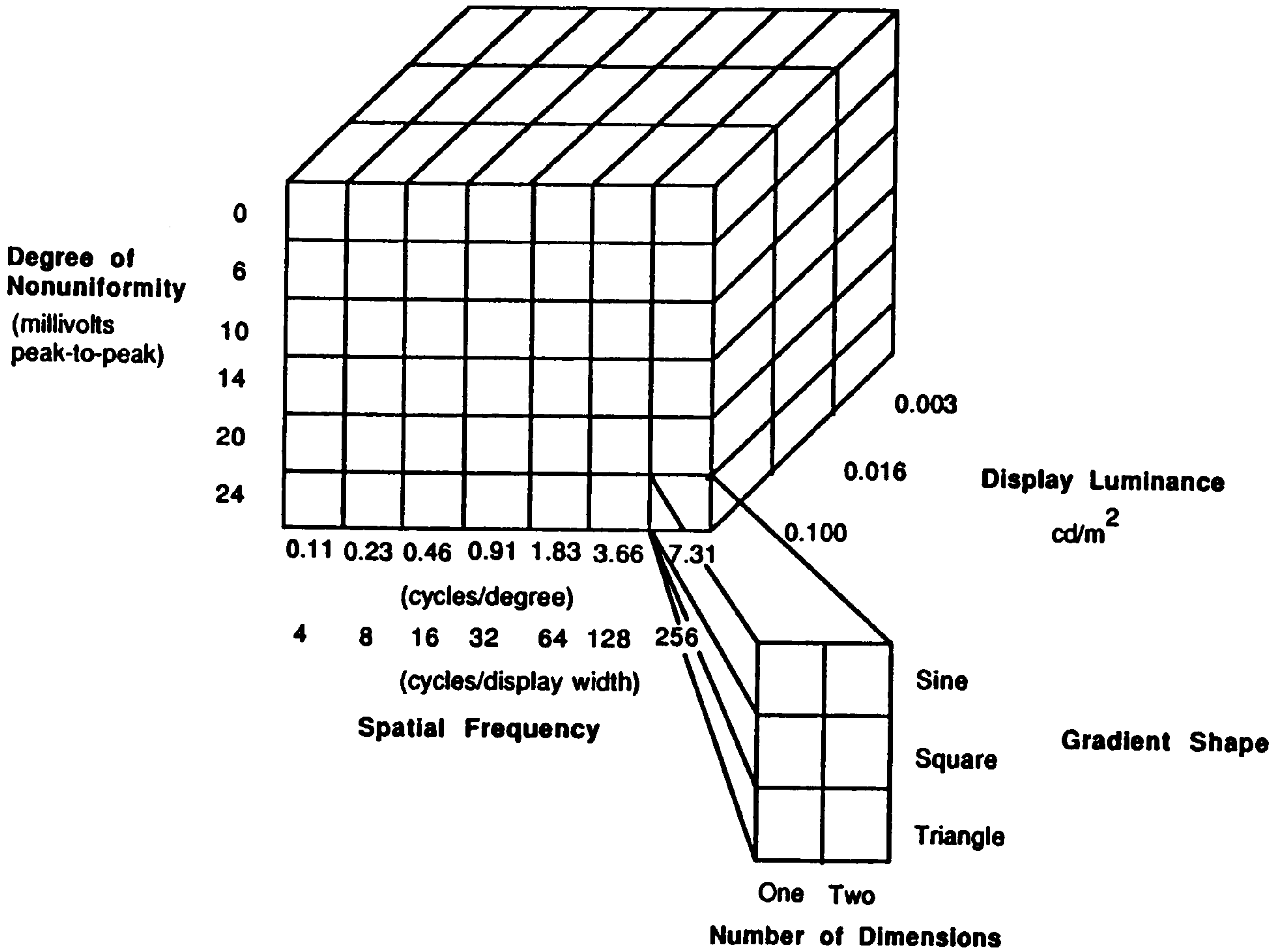


Figure 5. Experimental design.

Human Performance Tasks

Random search task. A non-contextual random search task was used in which the dependent measures were search time (ST) and the percentage of correct responses (CR). This task was chosen because research has shown that humans are able to perform contextual type tasks, such as reading tasks, under adverse conditions (Albert, 1975). Lloyd et al. (1988) found that the random search task was more sensitive to high frequency display failure nonuniformities than a Tinker Speed of Reading Task. For the random search task the gradient variable (G) was assigned as a between-subjects variable and all other variables were within-subjects, resulting in 252 conditions for each G. Each condition was repeated five times for a total of 1260 data points per subject. There were five subjects randomly assigned to each G level.

Magnitude estimation task. Although subjects may be capable of performing an objective task in the presence of nonuniformities, it is possible that nonuniformities may be esthetically displeasing. This task was included to determine subjective impressions of the nonuniformities. The magnitude estimation task required subjects to provide a magnitude rating of the perceived uniformity; that is, subjects rated how uniform the luminance appeared to them. Note that subjects were told to rate perceived uniformity rather than nonuniformity because nonuniformity can not be defined without biasing responses. However, subjects could understand the term uniformity. Higher numerical values indicated that subjects perceived the display as appearing more uniform. Instructions for this task are listed in Appendix B. The rating was the dependent variable. During pilot testing it was determined that if a rating scale was provided, subjects were unable to fit all their impressions onto the scale. With the free-modulus technique subjects could provide their own rating scale, which gave a better indication of their impressions. For this task, the variable DIM was treated as a between-subjects variable and all others as within-subjects, resulting in 378 conditions for each DIM. Each condition was repeated twice for a total of 756 data points per subject. Fifteen subjects were randomly assigned to each DIM condition.

Subjects

Forty-five students from Virginia Polytechnic Institute and State University served as subjects and were paid $5.00 per hour for their participation. Fifteen subjects participated in the random search task and 30 subjects in the magnitude estimation task. Subjects participated in the random search task 5 days, 2 hours per day. Subjects participated in the magnitude estimation task for 2 days, 2 hours per day. All subjects were between the ages of 18 and 30 with a mean age of 20.5. Each subject was screened for normal or corrected 20/22 near and distant vision, and normal lateral and vertical phoria using a Bausch & Lomb Orthorater. Each subject was also screened for normal near and far contrast sensitivity using a contrast sensitivity test by Vistech Consultants Inc.

Measurement Apparatus

Imaging system. The imaging system consisted of a 48.3-cm diagonal monochrome cathode-ray tube (CRT), a video signal generator, two programmable function generators, a custom built horizontal line generator (HLG), and an IBM-PC AT. Figure 6 is a block diagram of the system.

The CRT monitor was a high resolution GMA-201 manufactured by Tektronix, Inc. (part # 070-5079-00). The monitor was driven at 60 Hz non-interlaced with an addressability of 1024 x 1024 pixels within an active area of 27.94 cm^2. The CRT had a standard P4 phosphor and was interfaced with an OPIX video signal generator produced by Quantum Data. The OPIX was capable of a 200-MHz pixel rate with a nominal rise/fall time of 1.8 ns.

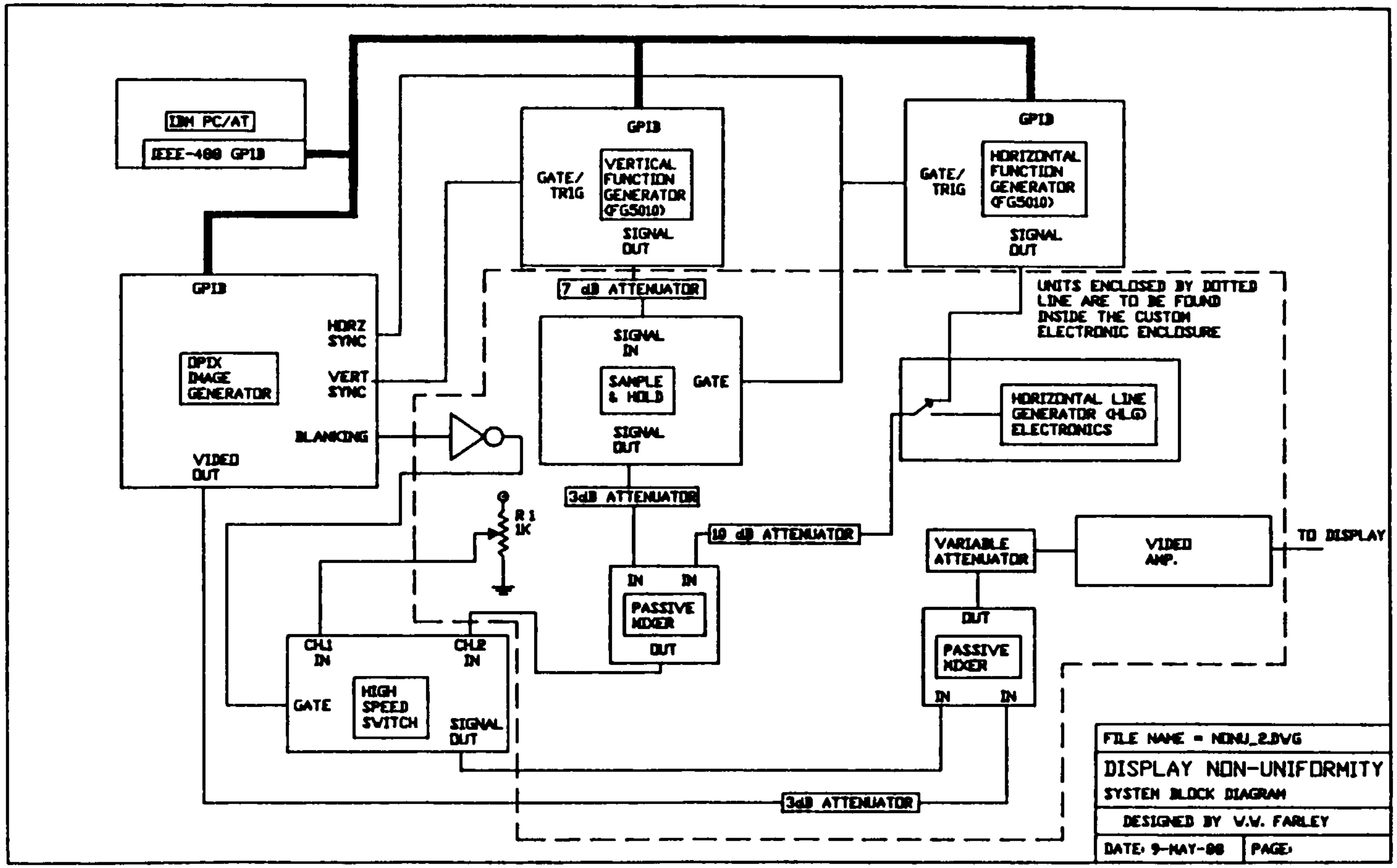


Figure 6. Block diagram of the imaging system.

Two programmable function generators (Tektronix, model 5010) produced the nonuniformities. The generators controlled the A, DL, and F of the nonuniformities. One function generator was used to produce vertical nonuniformities and one to produce horizontal nonuniformities. Each generator was capable of a frequency range of 0.002 Hz to 20 MHz and output amplitudes of 20 mv to 20 v peak-to-peak. The generators were triggered and synchronized by the OPIX and had a frequency stability of 0.10% (Tektronix, 1982). Table 4 lists the amplitude and frequency values for both the vertical and horizontal function generators and the frequency accuracy ranges for each wave shape (Tektronix, 1982).

As illustrated in Figure 6, the vertical and horizontal synch from the OPIX triggered the vertical and horizontal function generators. The output of the vertical generator was attenuated by 6 dB and the horizontal generator by 10dB (not shown in the figure) before the signal was input to the custom electronic enclosure. Vertical and horizontal nonuniformities were synchronized using a sample and hold amplifier (model CLC940A1) by Comlinear Corp. output from both generators was then sent to a passive mixer. The output from the mixer was then sent to a high speed switch to be synchronized with the blanking signal from the OPIX. The signal out of the high speed switch was sent to another passive mixer which added the nonuniformity signal and the OPIX video output signal. The output from the mixer was amplified by a linear video signal amplifier (model CLC 100 by Comlinear Corp.) before being sent to the display.

The function generators were not phase-locked to the OPIX or display. When a square wave shape from the horizontal function generator was presented, the horizontal lines on the display would flicker on and off. Therefore, a custom built horizontal line generator (HLG) was used to generate the square-wave shapes for the horizontal signal. The HLG was capable of controlling the F, A, and DL values and values were set to match the output of the vertical and

TABLE 4

Frequency and Amplitude Settings and Function Generator Accuracy Ranges for each Wave Shape.

Amplitudes (Volts)		Frequencies (KHz)	
Vertical FG	Horizontal FG	Vertical FG	Horizontal FG
0.0	0.0	0.250	354 .00
0.069	0.784	0.484	737 .00
0.1388	1.546	1.031	1403.00
0.232	2.16	1.999	2890.00
0.394	3.14	4.02	5820.00
0.482	4.00	8.01	11120.00
		16.04	20000.00

Function Generator Accuracy Ranges

Accuracy Range			Square	Triangle	Sine
0.002 Hz	≤ f ≤	1 kHz	± 2.0%	± 2.0%	± 3.0%
1 kHz	< f ≤	100 kHz	± 3.5%	± 3.5%	± 3.50%
100 kHz	< f ≤	1MHz	± 3.5%	± 4.0%	± 3.5%
1 MHz	< f ≤	5MHz	± 5.0%	+ 4.0% , - 5.0%	± 5.0%
5 MHz	< f ≤	10 MHz	± 5.0%	+ 4.0%, - 20.0%	+ 5.0%, -10.0%
10 MHz	< f ≤	20 MHz	± 10.0%	+ 4.0%, - 20.0%	+ 5.0%, -10.0%

horizontal function generators. The HLG was controlled manually and was only used for the SQ 2-D nonuniformities because the 1-D nonuniformities were vertical.

During measurements the IBM-PC AT was used as a terminal to control the OPIX and the programmable function generators. The function generators and OPIX were interfaced to the IBM-PC AT using the General Purpose Interface Bus (GPIB) communications system.

Measurement system. Figure 7 is a diagram of the microphotometric measurement system used to make spatial luminance measurements. The system was composed of a telemicroscope (GS-2110); photomultiplier tube (PMT) with a photopic correction filter (D46-A); an x, y, z stage for microscope positioning; a stainless steel optical table; an intelligent radiometer (GS-4100); and an IBM-PC XT. The telemicroscope, PMT, and radiometer were produced by EG&G Gamma Scientific. A 1.0X objective lens and a 0.010 mm x 3.0 mm scanning slit aperture were used for all measurements. The steel optical table was air-cushioned to isolate the measurement system and display from high frequency noise. The table was produced by Technical Manufacturing Corporation.

A CS100 hand held spot photometer by Minolta was used to perform area luminance measurements and to calibrate the CRT. The CS100 had a measurement area of 2 degrees and was mounted on a tripod during calibration and measurements for stability.

A digital oscilloscope by Tektronix (11042) was connected to the imaging system to determine the output voltages that were being sent to the display. The oscilloscope was connected to a special synch function in the OPIX which acted as an oscilloscope trigger. This allowed observation of a signal during a horizontal scan line at any particular time during the frame period.

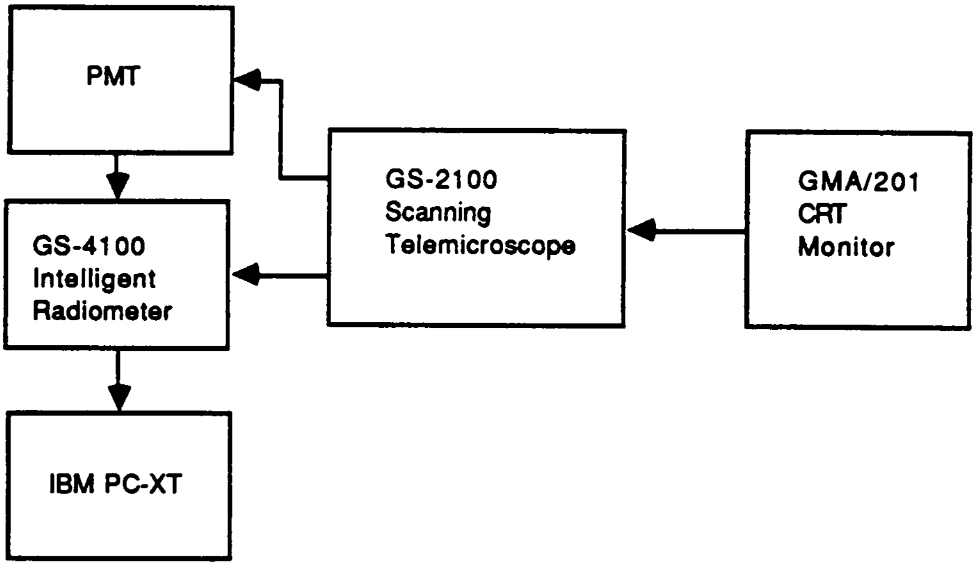


Figure 7. Block diagram of the measurement system.

Measurement Procedure and Analysis

Initially, cycles of each nonuniformity condition were to be measured on the display using the microphotometric measurement system to determine the actual output modulations at each spatial frequency. These values could then be used as input into a Fast Fourier routine to determine the coefficients of the nonuniformity patterns. However, the nonuniformity luminance (DL) levels used in this study were too low to be measured accurately by the spatial luminance microphotometric system. Instead the description of the nonuniformities in terms of their Fourier coefficients was determined analytically based on the theories of Fourier analysis and linear systems analysis as described below.

Calibration. There was a 30-min warm-up period after the imaging system was turned on. All units of the imaging system were left on at all times throughout the measurement phase. The system was calibrated using the CS100 spot photometer. Each DL level was sent to the display and the output luminance was measured. If necessary, the luminance output was changed using the brightness knob on the CRT. Measurements were made for the horizontal and vertical function generators as well as the HLG.

Figures 8 and 9 illustrate that the vertical and horizontal function generators and the HLG were calibrated to produce the same outputs. Figure 8 is the luminance modulation for the DL X A conditions for the separate horizontal and vertical generator signals. Figure 9 shows the combined vertical and horizontal generator signal and the combined vertical and HLG signal for 2-D conditions for each DL x A condition. These graphs illustrate the near-perfect correspondence in output signals between the function generators and the HLG.

Display system gamma. The display system gamma is the function which relates the input voltage to the output luminance of the CRT. This function was determined by varying the input

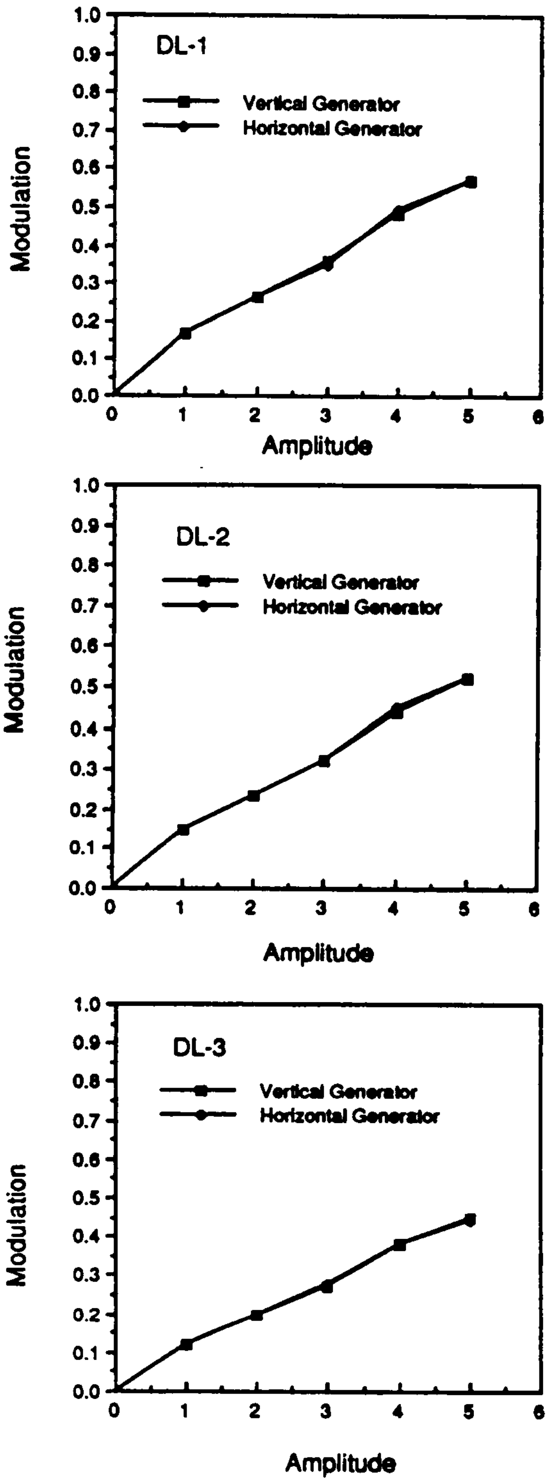


Figure 8. Luminance modulation for each A x DL condition for the vertical and horizontal function generators.

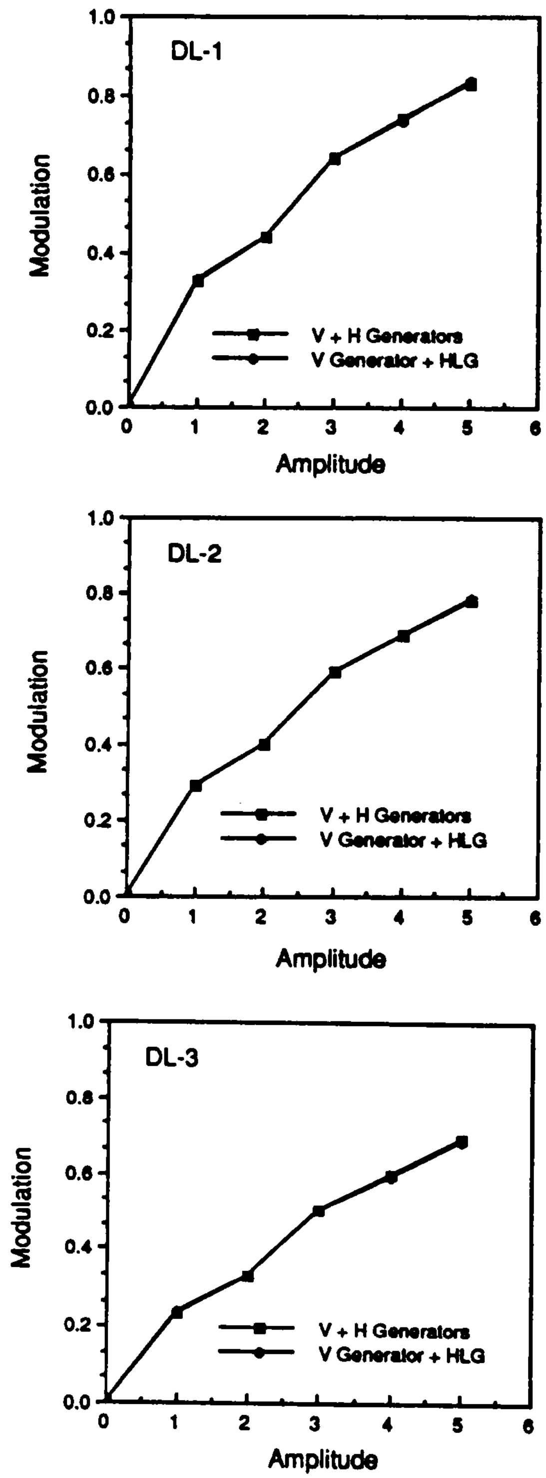


Figure 9. Luminance modulations for the combined vertical and horizontal function generators, and the combined vertical and HLG.

voltages and measuring the output luminance of the CRT with all pixels on. Luminance measurements were taken with the CS100 spot photometer. Input voltage was manipulated by changing the bit values into the display. The display was capable of 0 to 255 bit levels and the voltage levels corresponding to each bit level were displayed on the oscilloscope. Figure 10 illustrates the gamma function of the CRT. As illustrated by this figure, the luminance output of the CRT as a function of input voltage, for all practical purposes, is linear in the low luminance range. Therefore the application of linear systems analysis is viable for the luminance levels (i.e., less than 0.33 cd/m^2) used in this study.

Nonuniformity description. After obtaining the gamma function, the maximum and minimum luminance values for each A and DL level were determined. The nonuniformity was sent to the CRT and the input voltages were displayed on the oscilloscope. After determining the maximum and minimum voltages for each A level at each DL, the values were then converted to maximum and minimum luminance using the gamma function. In the case of 2-D nonuniformities, maximum and minimum luminance values were determined for the horizontal nonuniformity, the vertical nonuniformity, and the added vertical and horizontal nonuniformity as illustrated in Figure 11. Modulation A represents the vertical nonuniformity, modulation B represents the horizontal nonuniformity, and modulation C represents the added vertical and horizontal nonuniformities and is the maximum modulation displayed. An example of the final displayed pattern is illustrated in Figure 11c. Modulations for each A x DL condition were determined using luminance values in Equation 1.

It should be noted that the A x DL modulations are different for the 1-D and 2-D cases. Throughout the course of the experiment, the DL levels were manipulated by setting a constant offset on each function generator and by sending a constant bit level to the display for each DL condition. Therefore, the bit level and the output from the generators were added and describe

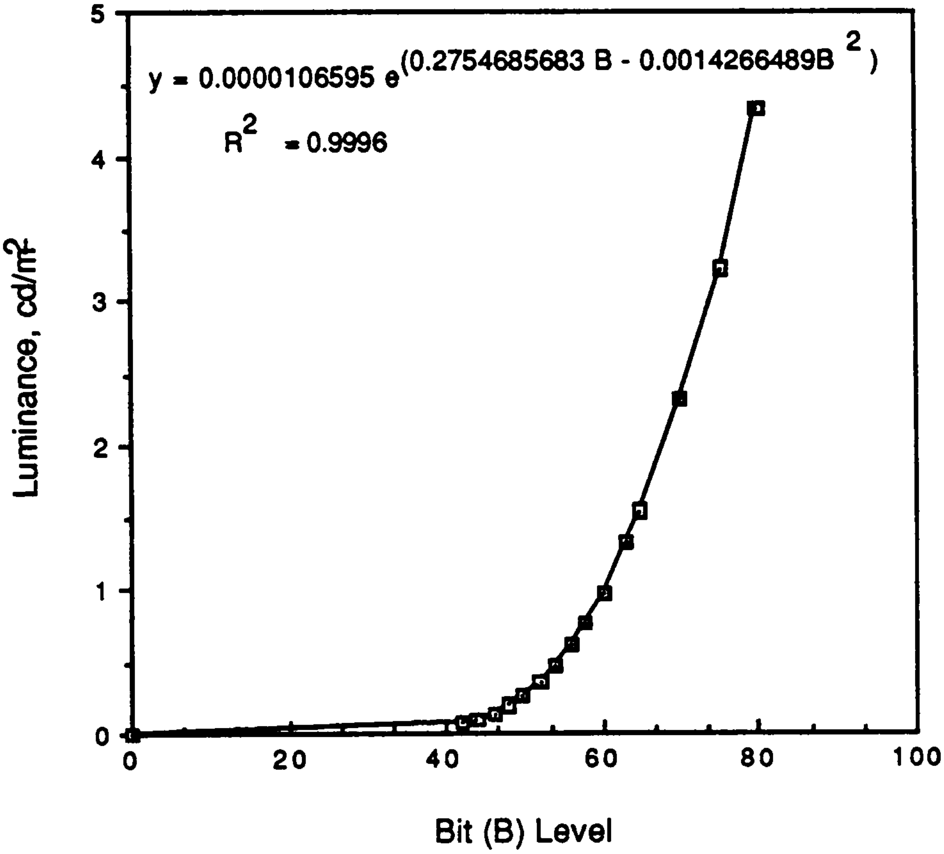
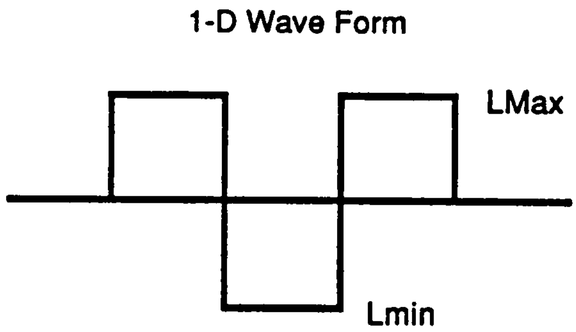
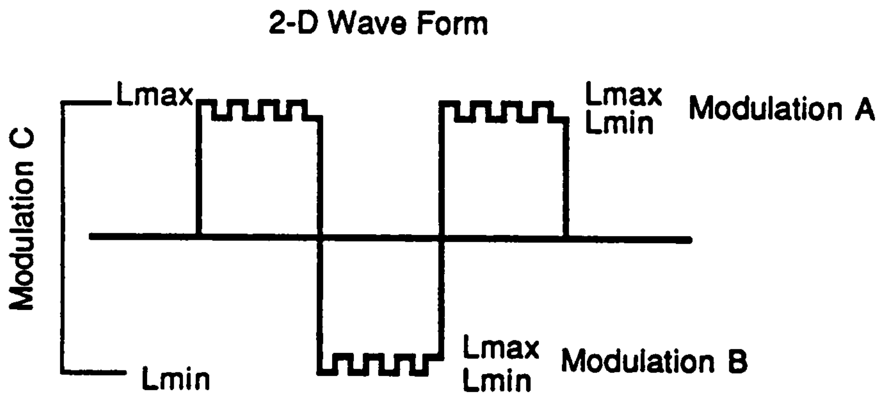


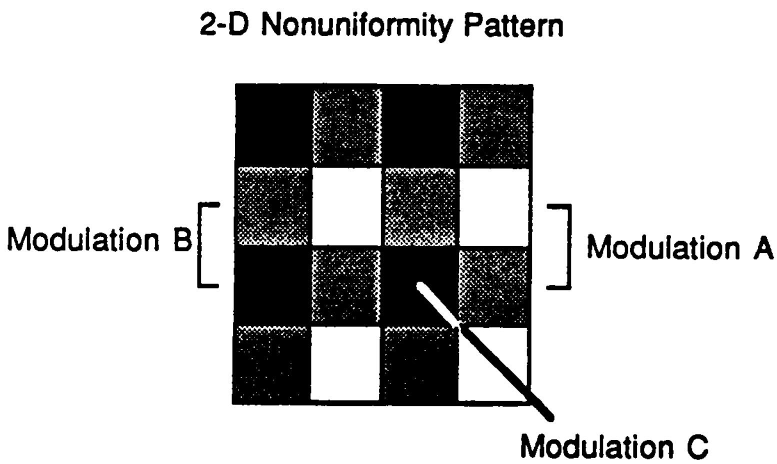
Figure 10. The CRT's gamma function.



a)



b)



c)

Figure 11. Example of 1-D and 2-D nonuniformity voltage measurements.

each DL level. In the case of the 1-D nonuniformity, the output on one of the function generators was disabled. Disabling the generator turned off the constant offset voltage being sent to the display from that generator; therefore, the DL levels for the 1-D conditions were lower than the 2-D conditions by the constant amount of 180 mv. Table 5 lists the DL levels in luminance for the 1- and 2-D conditions. Throughout this report, the DL levels will be discussed in terms of three levels, DL-1, DL-2, DL-3. The reader should keep in mind, however, that the DL levels did vary depending on the DIM.

Photometric measurements. The modulation transfer function (MTF) of the display system was determined through microphotometric measurements. The MTF can be obtained from the Fourier transform of a line spread function (LSF). The LSF was determined by scanning a single vertical line on the CRT. The output from this scan is luminance as a function of distance. As stated previously, the photometric system was unable to measure the low modulation levels used in this study; however, at these levels it was assumed that the display system gamma was linear. Several LSF measurements were taken of a vertical line set to maximum luminance values of 0.40 to 1.0 cd/m^2. The MTFs from these measurements were compared and found to be almost identical, supporting the assumption that the display system's output was in fact linear in these ranges. Therefore, the MTF values for a measurable luminance level could be used in subsequent analysis. The LSF and resulting MTF for the 1.0 cd/m^2 are shown in Figure 12 and were the MTF values used to describe the display system.

Fourier descriptions of the nonuniformities. The measurement data provided by the procedures described in the preceding sections were used to determine the Fourier coefficients for each nonuniformity condition. The procedure for obtaining the coefficients was analytical and was based on the Fourier Series, as briefly discussed below for purposes of explanation.

TABLE 5.

Display Luminance (DL) Values (cd/m^2) for 1- and 2-Dimensional Conditions.

DL	1-Dimensional	2-Dimensional
DL-1	0.0037	0.0215
DL-2	0.0167	0.0752
DL-3	0.1033	0.3352

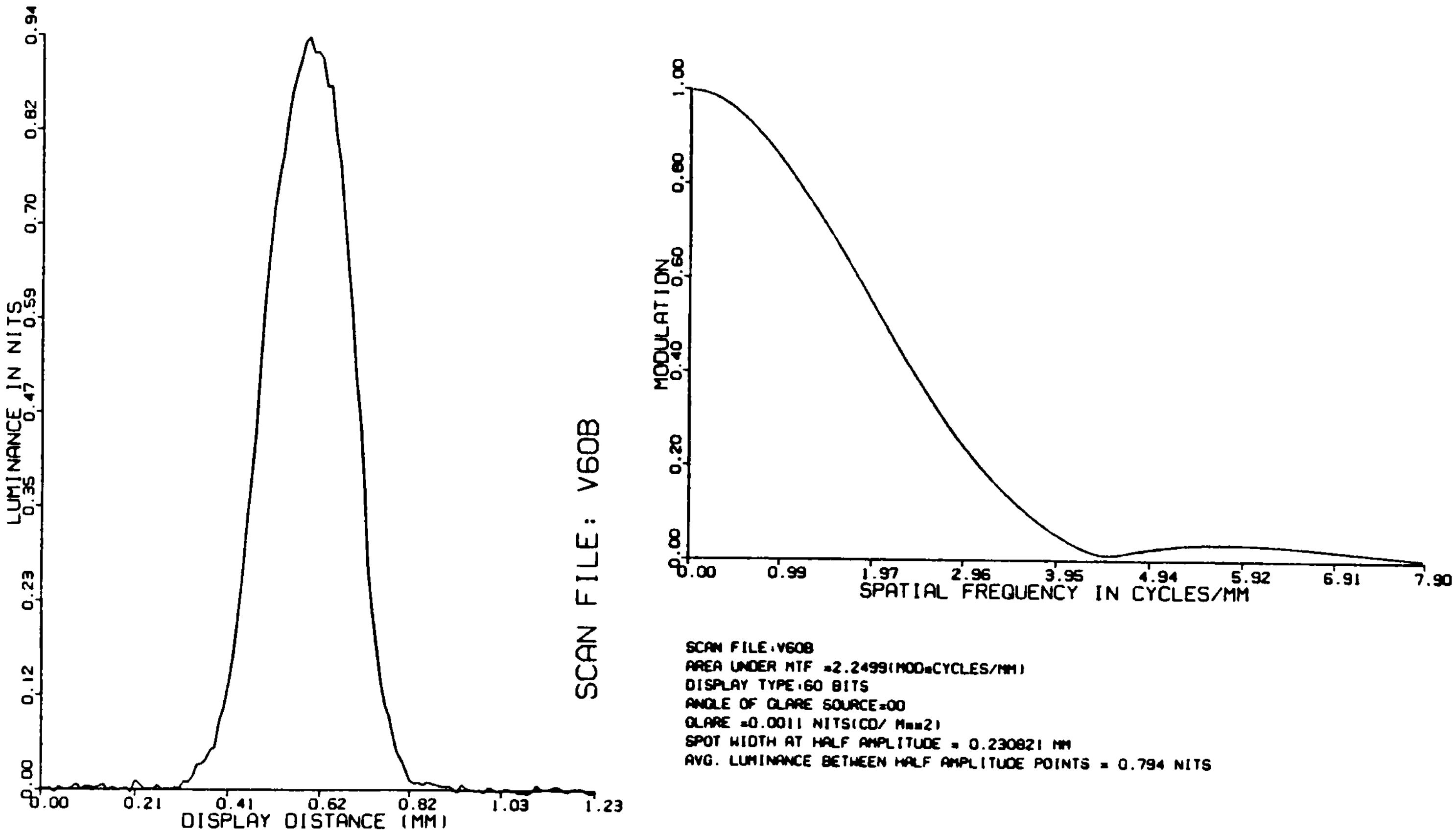


Figure 12. LSF and MTF of the CRT.

The general form of the Fourier Series is expressed as

$$x(p) = a_0 + \sum (a_n \cos n\, \omega_0 p + b_n \sin n\, \omega_0 p), \tag{3}$$

where ω_0 is the spatial frequency. The components of the series a_0, a_n, and b_n describe the frequency content of the image. The a_0 coefficient is the average value of the function x(p) over one period (P) or its DC level. The first component of the series for $n = 1$ is the fundamental frequency component. Additional components of the series are integer multiples of the fundamental and are called harmonics. The coefficients can be determined by

$$a_0 = \frac{1}{P}\int_0^P x(p)\, dt, \tag{4}$$

$$a_n = \frac{1}{P}\int_0^P x(p) \cos n\, \omega_0 P / dt, \tag{5}$$

$$b_n = \frac{1}{P}\int_0^P x(p) \sin n\, \omega_0 P / dt, \tag{6}$$

The Fourier series for common wave forms are widely published . When the coefficients are evaluated for a square wave, they result in the series;

$$x(p) = \frac{4V}{\pi}(\cos \omega_0 p - \frac{1}{3}\cos 3\omega_0 P + \frac{1}{5}\cos 5\omega_0 P - \frac{1}{7}\cos 7\omega_0 P ......), \tag{7}$$

where $\omega_0 = 2\pi / P$, P is one cycle of the wave form, and V is the half-amplitude of the wave form. For the triangular wave form the series is

$$x(p) = \frac{8V}{\pi^2}(\cos \omega_0 p - \frac{1}{3}\cos 3\omega_0 P + \frac{1}{5}\cos 5\omega_0 P - \frac{1}{7}\cos 7\omega_0 P ......), \tag{8}$$

The Fourier coefficients (in displayed luminance amplitude) for the nonuniformities were derived from the Fourier series equations. The nonuniformities used in this study were described in terms of F, A, and waveform (or G); therefore, these data can be used in the above equations to determine the coefficients for each nonuniformity condition. The half amplitudes (cd/m^2) for each A x DL condition were input into the Fourier series equations to determine the amplitude of the fundamental frequency component and harmonics for each nonuniformity condition. For the 2-D conditions, the half amplitude of the highest modulation on the display was used in this analysis as illustrated in Figure 11. If subjects were unable to detect the highest modulation, then they would be unable to detect the lower modulations.

The MTF describes the display system spatial frequency response; therefore, the amplitude coefficients at each ω_0 were multiplied by the MTF value at ω_0 to determine the output displayed luminance amplitude. The displayed luminance amplitude was then converted to modulation values using Equation 1.

Appendix A is a series of tables which list the displayed luminance modulations (DLM) for the fundamental and the first three harmonic frequencies of interest for each nonuniformity condition. Each individual table represents an F x DL x DIM condition. Within each table are the DLM values for the A x G conditions. The CTF value listed in the table represents the CTF value at each particular spatial frequency. If the DLM is greater than the CTF value, then the frequency component is visible to the observer, or above his or her visual detection threshold. The row labeled detection indicates whether the frequency component is visible by indicating Yes or No. Notice that as F increases, modulations required for detection generally increase, the ability of the display to pass the modulation decreases, and detection is no longer possible for higher harmonics as indicated by the No responses in the tables.

The CTF values found in Appendix A were determined from Figure 3, which shows the CTFs for different display luminance backgrounds found by van Meeteren et al. (1968) as reported by Snyder (1980). The CTF for 0.10 cd/m^2 was used based on the DL levels used in this study.

The half amplitudes (cd/m^2) are listed at the end of Appendix A so that exact luminance values can be replicated. Note that the a_0 value (or DC levels) are included in the Appendix for each A x DL condition.

Human Performance Apparatus and Stimuli

Imaging system. The imaging system was the same as that described in the Measurement Apparatus section. A Microsoft Systems mouse was used as an input device and was connected to the IBM-PC AT.

Random search task stimuli. The map patterns and symbols were generated by the OPIX video signal generator. There were 26 U.S. Army symbols constructed in an 11 x 15 matrix size, as shown in Figure 13. The 11 x 15 matrix subtended 19 x 26 arcminutes of visual angle. Numbers were used as identification tags for the symbols and were created in the upper case 11 x 15 Lincoln-MITRE font. The map patterns were generated by an algorithm which drew lines on the display in a pseudo-random fashion. The lines were 1 pixel wide. Figure 14 is an example of a map with symbols. The symbols and maps were presented at a bit level of 65 which corresponded to a luminance level of approximately 4.13 cd/m^2. Note, however, that the symbol luminance was added to the DL levels so symbol and map luminance values were actually higher. When the nonuniformities were also added, the luminance of the symbols increased more when the symbol fell on the light portion of a cycle than when they fell on a dark portion of a cycle. The modulations of the symbols and maps varied for each DL level. For the 1-D conditions the modulations were approximately 0.998, 0.992, and 0.951 for DL-1, DL-2, and DL-3, respectively. For the 2-D

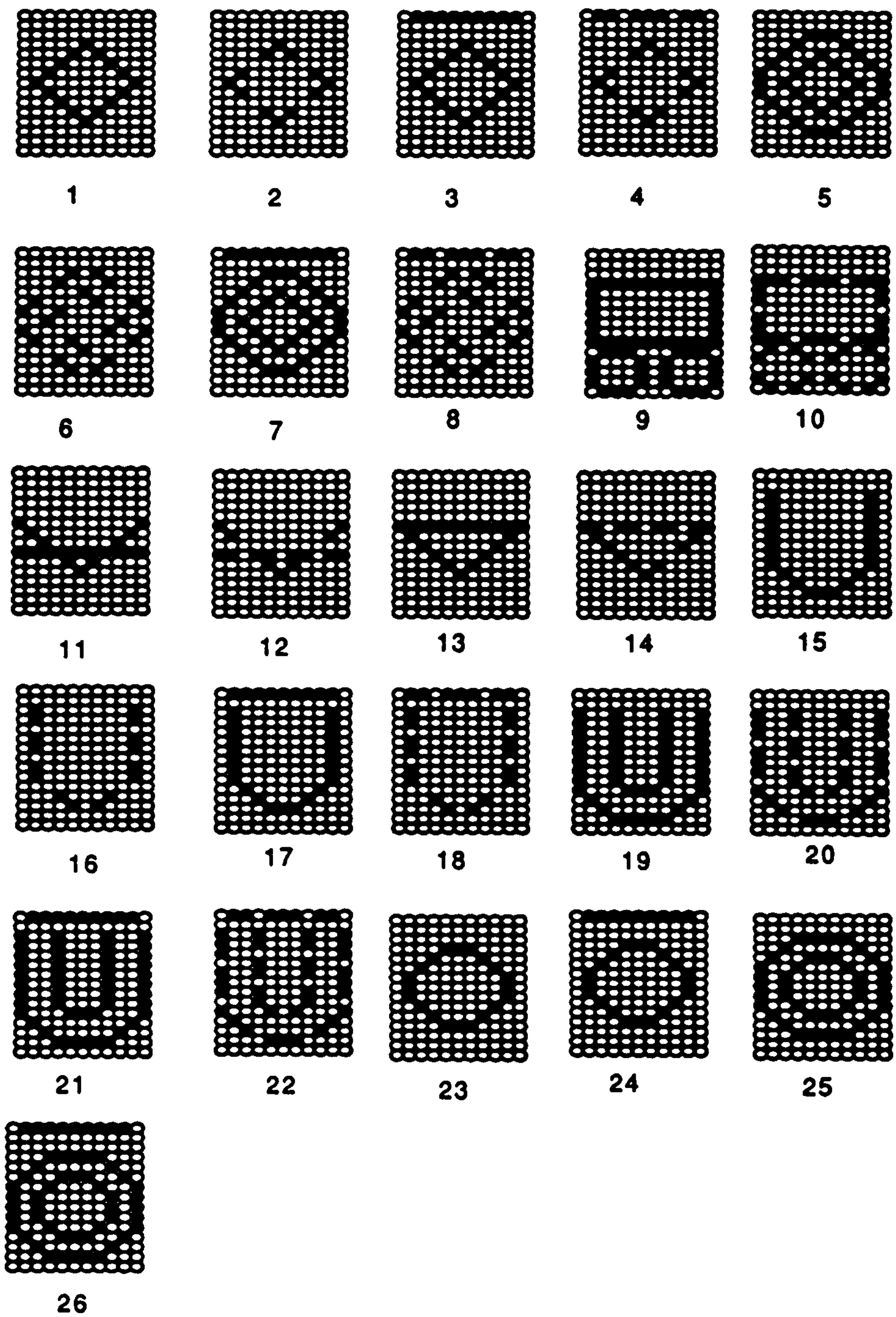


Figure 13. Random search task symbols

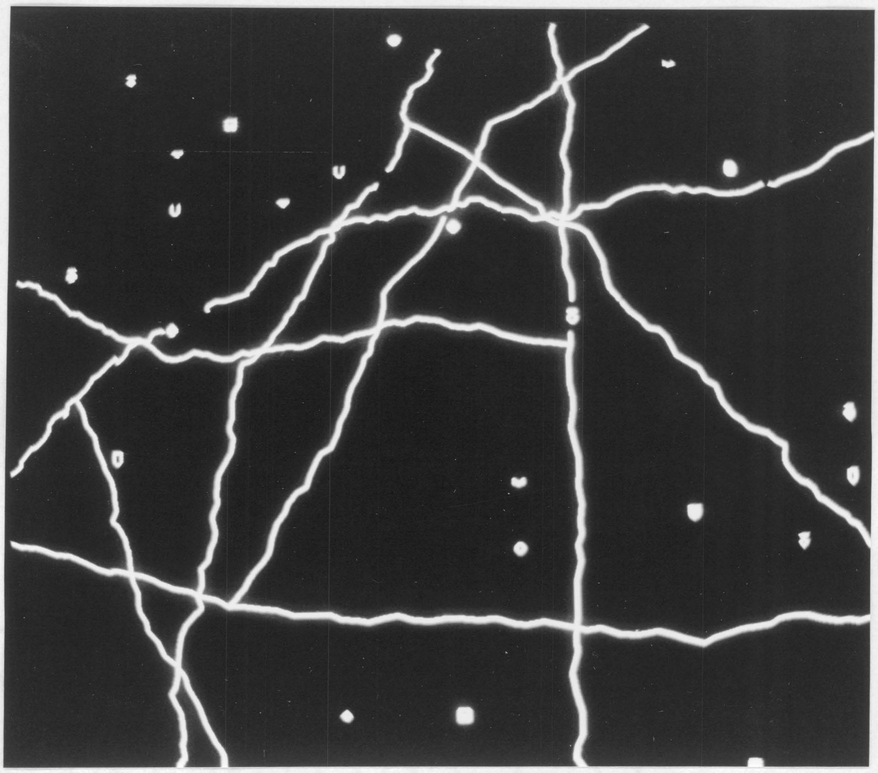


Figure 14. Photograph of a random search pattern with map.

conditions the modulations were approximately 0.989, 0.992, and 0.849 for DL-1, DL-2, and DL-3.

The nonuniformity patterns were created using the function generators. The parameters of F, A, G, and DL were sent to the function generators via the GPIB bus system from the IBM-PC AT.

Magnitude estimation task stimuli. Stimuli consisted of the nonuniformity patterns generated by the function generators and were the same as those used in the search task. Map and symbol information were not displayed. Figures 15 through 17 are examples of six nonuniformity patterns. These patterns represent the SINE, SQ, and TRI wave shapes at an F of 4 c/dw, for 1- and 2-D. Note that the photographs are high contrast examples and do not reflect the true (lower) modulations displayed on the CRT.

Human Performance Procedure.

At the beginning of each experimental session the display was calibrated using the CS100 spot photometer. The luminance of the display at each DL level was checked with the input from each function generator and the HLG. The nonuniformity patterns were also checked at each spatial frequency to be sure that all generators functioned properly. Ambient illumination was set to produce approximately 0.20 cd/m^2 luminance on the back wall.

During the first day of an experimental session, subjects read and signed an informed consent form. At the beginning of each session the instructions were read aloud by the experimenter. Instructions for both tasks are listed in Appendix B. Subjects were seated in front of the display and the height and distance of their chair were adjusted. On the first day subjects participated in 10 practice trials to become familiar with the procedures.

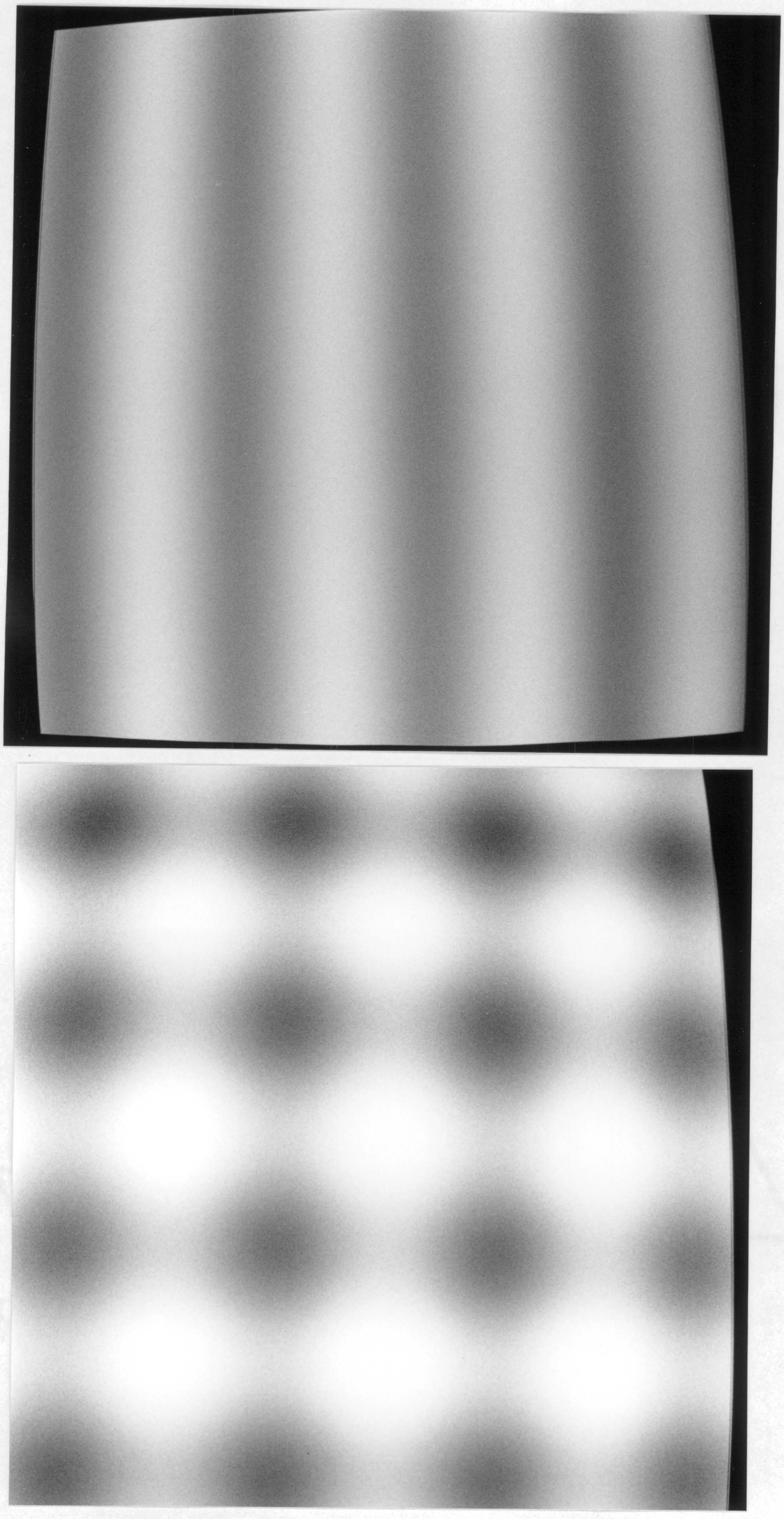


Figure 15. Photograph of 1-D and 2-D SINE at 4 c/dw.

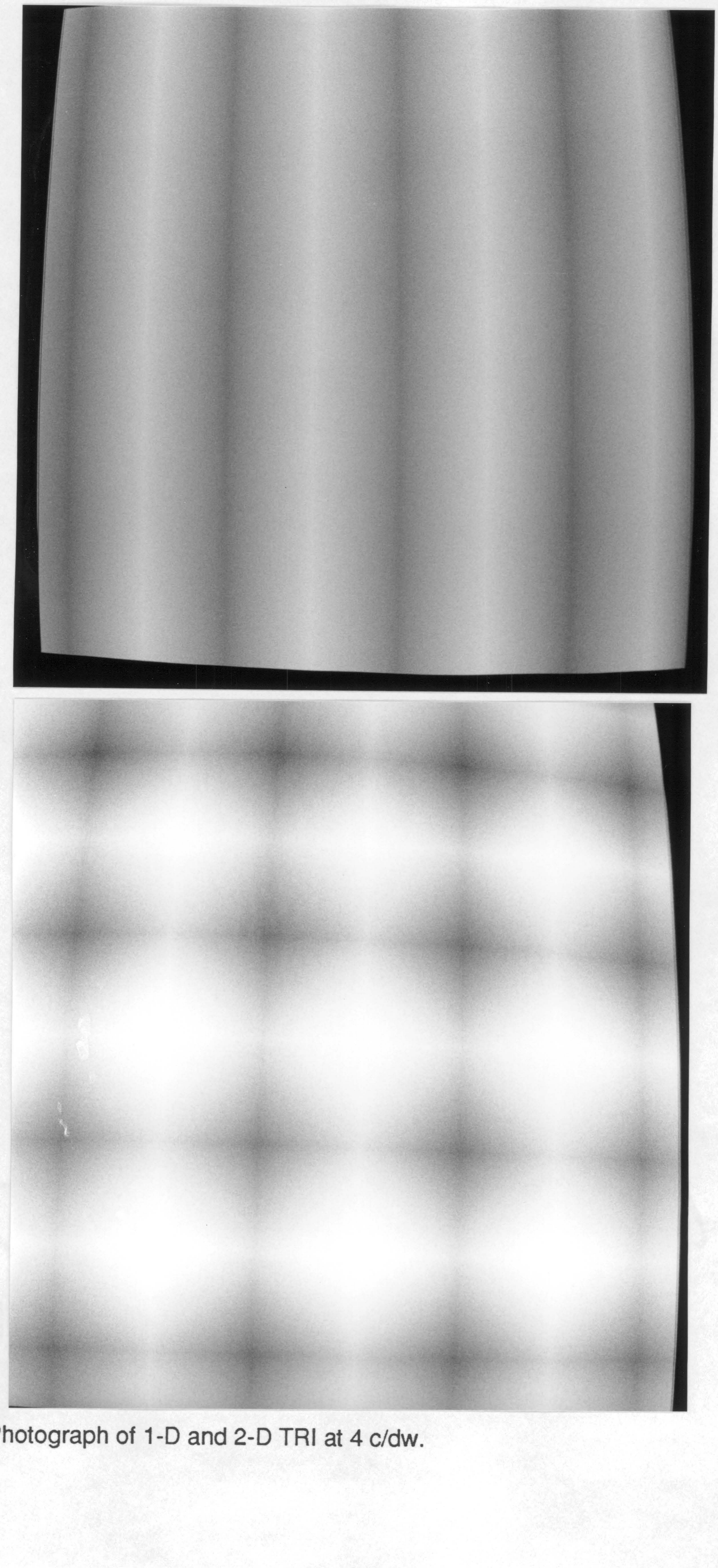


Figure 16. Photograph of 1-D and 2-D TRI at 4 c/dw.

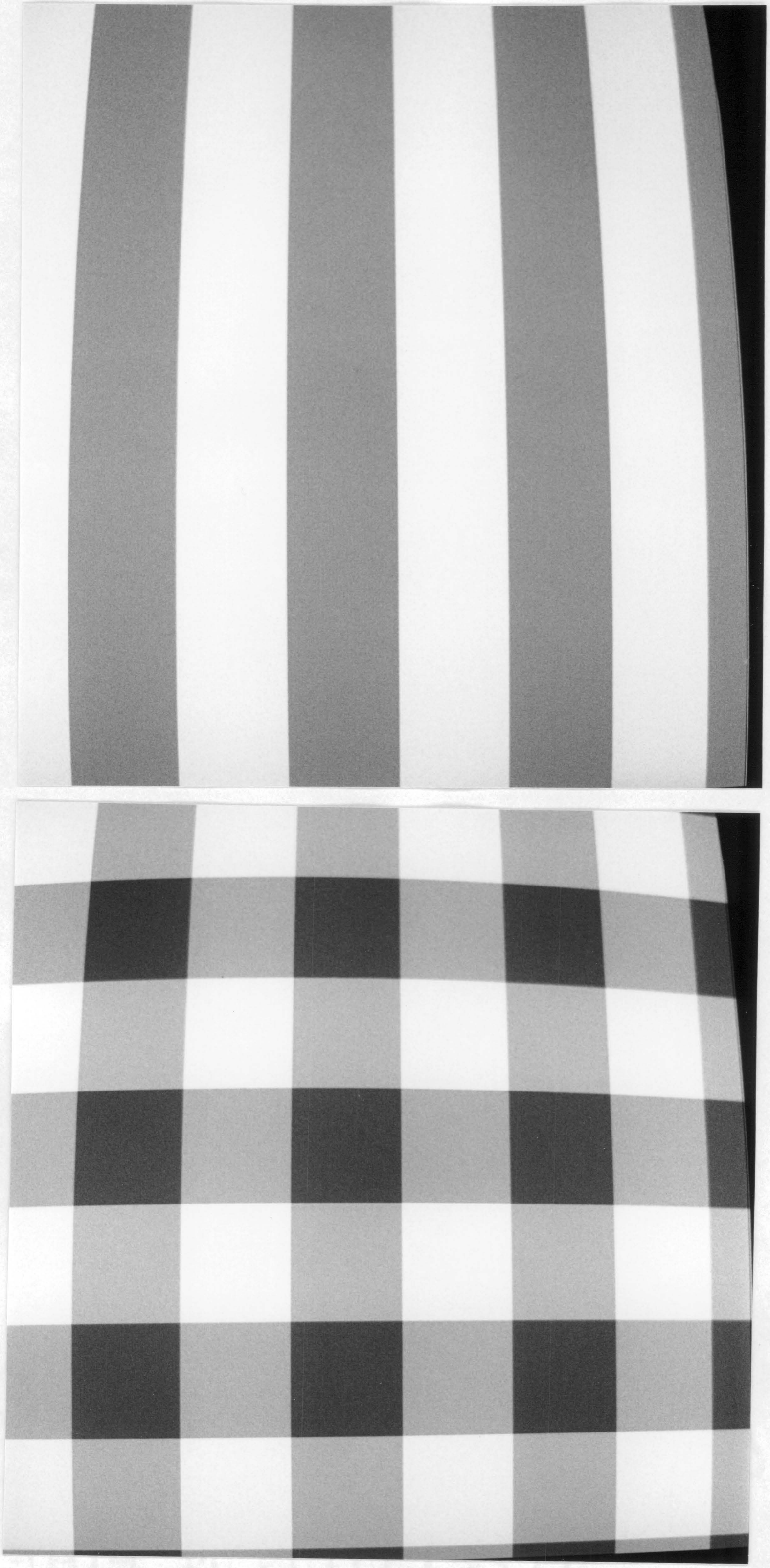


Figure 17. Photograph of 1-D and 2-DSQ at 4 c/dw.

Random search task. Before beginning the experimental sessions, the symbols were presented on the screen and subjects were given five minutes to become familiar with the symbols. This also gave subjects a chance to dark adapt. At the beginning of each trial a prompt was displayed on the screen which stated "Ready, the next target is _____", with the search target displayed. When subjects were ready to begin searching they pressed the button on the mouse input device and the map, 26 symbols, and nonuniformities were displayed. All symbols were randomly placed on the screen. Symbols and map lines never overlapped. After locating the target, subjects pressed the mouse button and the nonuniformity and symbols were removed. A symbol identification (ID) number was displayed in the area to the right of each symbol position. Subjects reported the symbol ID which corresponded to the target symbol they had found. The ID number was randomly selected for each symbol during each trial so that subjects could not memorize a specific ID number associated with a specific symbol. Subject responses were input to the computer by the experimenter. Responses were timed from the onset of the first button press to the second button press using the IBM-PC clock function. The clock had a resolution of plus or minus 55 ms. There were 5 trials per condition, resulting in 1260 trials per subject. All trials were presented in random order.

Magnitude estimation task. After reading the instructions subjects were dark adapted for five minutes. At the beginning of each trial a READY prompt was displayed. When subjects were ready to give their perceived uniformity ratings they pushed the button on the mouse input device and a nonuniformity pattern was displayed. Subjects were given as much time as they needed to report their ratings. The ratings of perceived uniformity were input to the computer by the experimenter. There were two trials per condition, resulting in 756 trials per subject. All trials were presented in random order.

RESULTS AND DISCUSSION

Random Search Task

For each subject, the mean of the five trials per condition was calculated and used in subsequent analyses. Analysis of variance (ANOVA) procedures were then performed on the dependent variables search time (ST) and percentage of correct responses (CR) over the five trials/condition using the Statistical Analysis System (SAS, version 5.18) on an IBM 3090. Post-hoc simple-effect F-tests were performed to evaluate significant interactions, and the Newman-Keul comparisons test was performed to compare means.

Search time. Results of the 7 x 6 x 3 x 3 x 2 (F x A x DL x G x DIM) repeated-measures mixed factorial analysis of variance (ANOVA) are listed in Table 6. G was treated as a between-subjects variable and all other variables as within-subjects. Discussed below are two third-order effects (F x A x DIM, DL x G x DIM), one second-order effect (A x DIM), and the main effect of DL.

Figure 18 illustrates the F x A x DIM interaction ($p = 0.0562$). The results of a simple-effect F-test by DIM are shown in Table 7. The F x A interaction is significant ($p = 0.0422$) for the 1-D condition; however, even for the 1-D level, it is difficult to interpret the F x A interaction. Higher levels of A do not necessarily result in longer STs, nor is there any pattern to the F effect.

Figure 19 shows the DL x G x DIM interaction ($p = 0.0303$). This figure illustrates that for both the 1- and 2-D conditions, STs were faster for SINE waves than for TRI or SQ waves. Also, as DL increased, ST in general decreased. A simple-effect F-test (Table 8) indicated no significant G x DL interaction for either DIM. Table 9 lists the results of simple-effect F-tests for DL x DIM at each G. A significant interaction between DIM and DL for the SQ wave was indicated. For the 2-D SQ wave there appears to be little difference among the three DL levels, although there is a slight

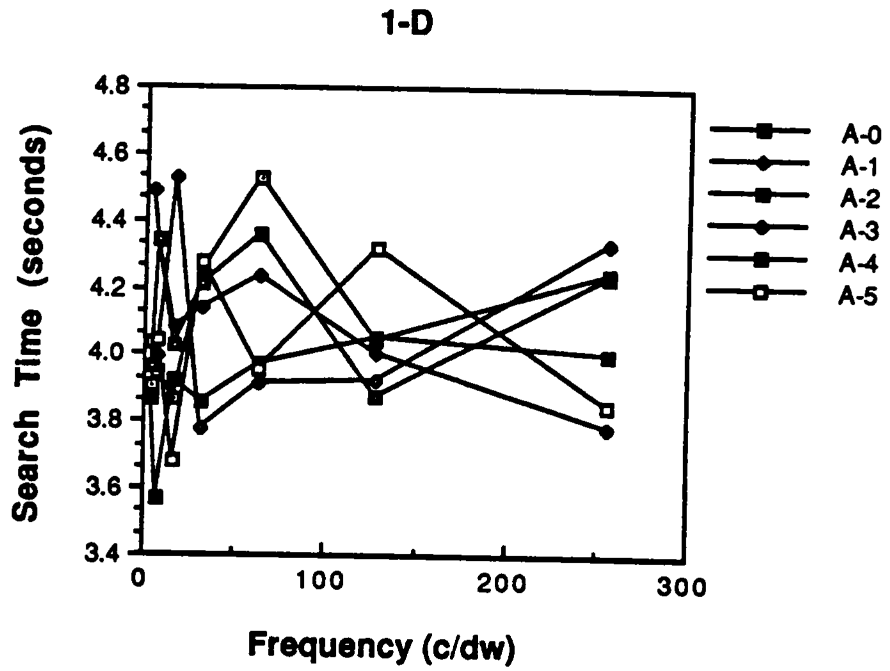
Table 6

Analysis of Variance Summary Table for Search Time

Source of Variance	df	MS	F	p
<u>Between Subjects</u>				
Gradient (G)	2	1328412.88	1.20	0.3355
Subjects(S/G)	12	1109011.59		
<u>Within Subjects</u>				
Frequency (F)	6	18796.59	1.53	0.1793
F*G	12	11253.70	0.92	0.5332
F*Sub(G)	72	12250.62		
Amplitude(A)	5	6034.79	0.38	0.8617
A*G	10	9935.24	0.62	0.7886
A*(S/G)	60	15956.35		
Display luminance (DL)	2	255152.94	8.50	0.0016
DL*G	4	10562.03	0.35	0.8403
DL*(S/G)	24	30033.82		
Dimension (DIM)	1	21.24	0.00	0.9786
DIM*G	2	1008.81	0.04	0.9650
DIM*(S/G)	12	28218.21		
F*DL	12	17338.27	1.00	0.4523
F*DL*G	24	20420.41	1.18	0.2721
F*DL*(S/G)	144	17342.08		
F*A	30	24707.93	1.34	0.1144
F*A*G	60	21500.02	1.16	0.2024
F*A*(S/G)	360	18459.40		
F*DIM	6	14029.49	0.81	0.5675
F*DIM*G	12	15688.06	0.90	0.5482
F*DIM*(S/G)	72	17374.20		

TABLE 6 (CONT)

Source of Variance	df	MS	F	p
A*DL	10	27014.62	1.68	0.0920
A*DL*G	20	19412.38	1.21	0.2577
A*DL*(S/G)	120	16038.59		
A*DIM	5	37736.41	2.29	0.0568
A*DIM*G	10	22369.62	1.36	0.2218
A*DIM*(S/G)	60	16470.07		
DL*DIM	2	1689.47	0.14	0.8666
DL*DIM*G	4	37648.55	3.21	0.0303
DL*DIM*(S/G)	24	11729.84		
F*A*DL	60	15240.46	0.85	0.7800
F*A*DL*G	120	16905.46	0.94	0.6454
F*A*DL*(S/G)	720	17898.35		
F*A*DIM	30	24075.10	1.47	0.0562
F*A*DIM*G	60	21257.72	1.30	0.0792
F*A*DIM*(S/G)	360	16370.53		
A*DL*DIM	10	21057.11	1.21	0.2912
A*DL*DIM*G	20	16507.27	0.95	0.5282
A*DL*DIM*(S/G)	120	17398.84		
DL*DIM*F	12	15593.40	0.88	0.5683
DL*DIM*F*G	24	16486.60	0.93	0.5606
DL*DIM*F*(S/G)	144	17711.19		
F*A*DL*DIM	60	18315.08	1.09	0.3082
F*A*DL*DIM*G	120	17692.60	1.05	0.3481
F*A*DL*DIM*(S/G)	720	16837.33		
Total	3779			



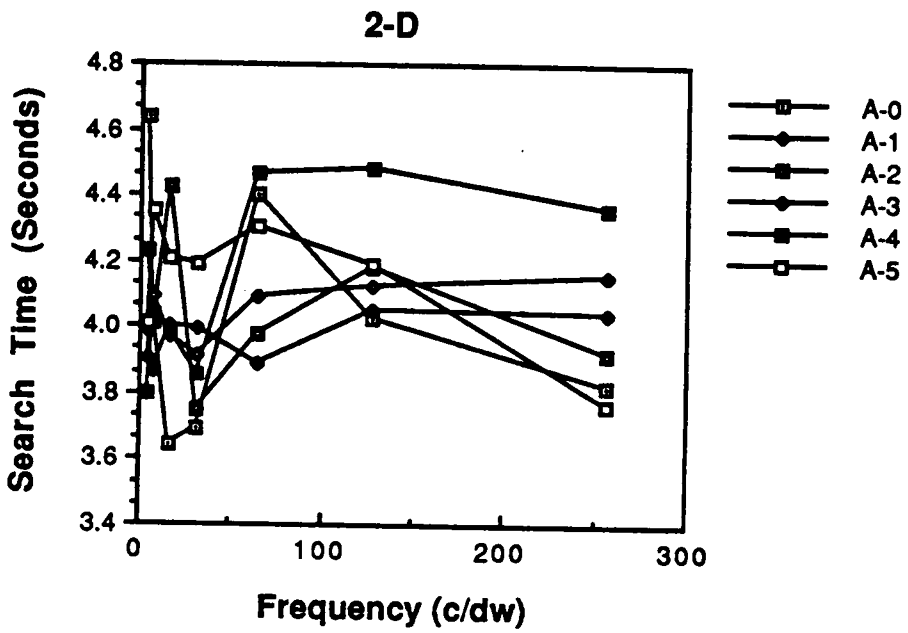


Figure 18. The F x A x DIM interaction for search time.

TABLE 7

Simple-Effect F-tests for F x A for One and Two Dimensions - Search Time

Source of Variance	df	MS	F	p
F x A for 1-D	30	24915.77	1.52	0.0422
F x A for 2-D	30	2386.72	0.14	1.0000
F x A x DIM x S/G	360	16370.53		

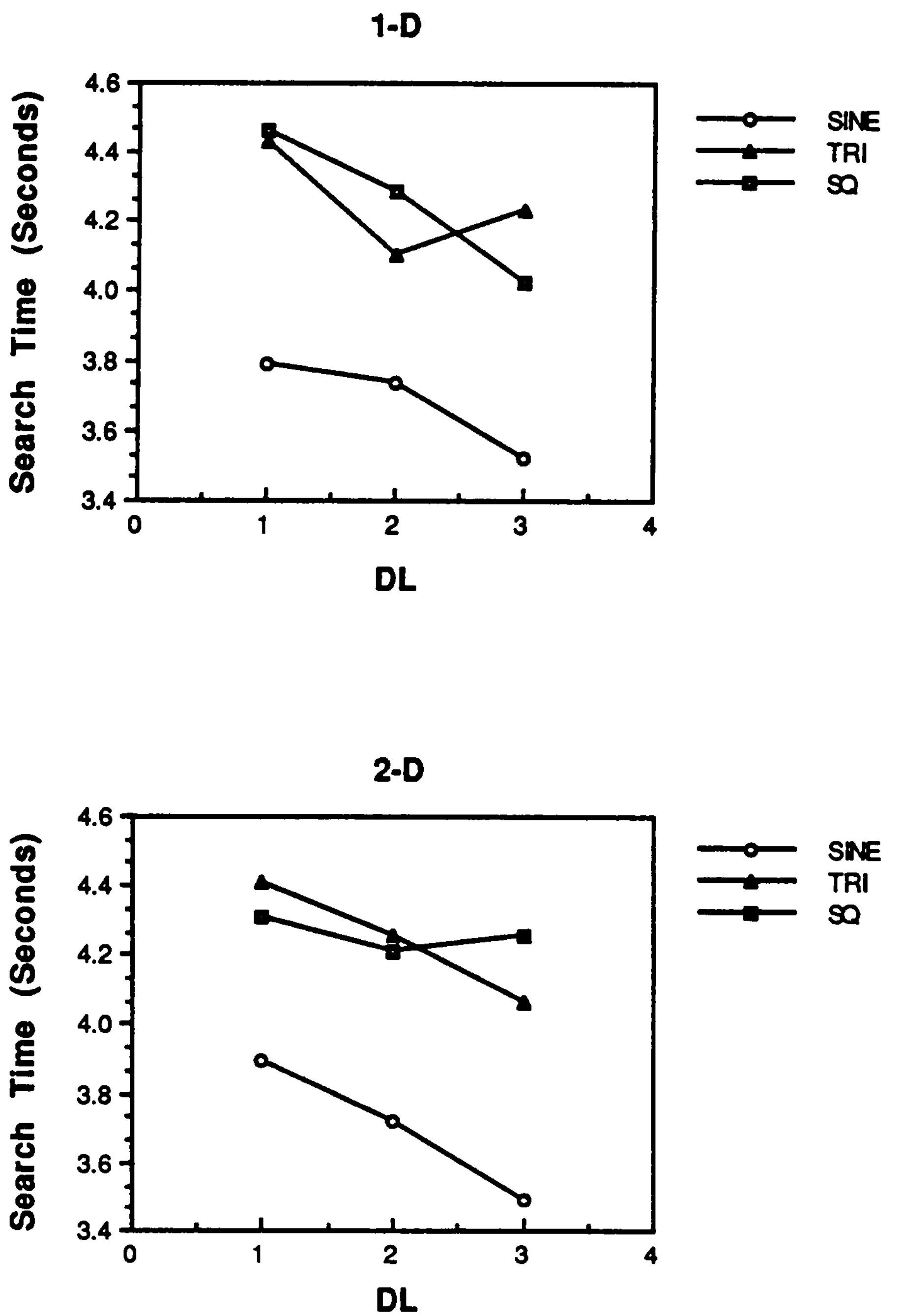


Figure 19. The G x DL x DIM interaction for search time.

TABLE 8

Simple-Effect F-tests for DL x G for One and Two Dimensions - Search Time

Source of Variance	df	MS	F	p
DL x G for 1-D	2	27710.47	2.36	0.1160
DL x G for 2-D	2	20500.11	1.75	0.1952
DL x DIM x S/G	24	11729.84		

TABLE 9

Simple-Effect F-tests for DL x DIM for Each Gradient - Search Time

Source of Variance	df	MS	F	p
DL x DIM for Sine	2	6195.99	0.53	0.5953
DL x DIM for Square	2	43503.28	3.71	0.0394
DL x DIM for Triangle	2	27287.29	2.33	0.1189
DL x DIM x S/G	24	11729.84		

increase in ST from DL-2 to DL-3. For the 1-D case ST decreased as DL increased. For the SQ wave the highest level of DL for the 2-D condition did not decrease ST probably because the nonuniformity pattern was beginning to interfere with performance, reducing the benefit of higher DL levels.

The A x DIM interaction is shown in Figure 20. STs were longer for the 1-D condition in all but two of the A conditions, A-0 and A-4. Table 10 lists the results of F-tests by A. There is a significant difference between DIMs for the A-4 condition only. There are no significant differences among A levels for either of the two DIMs.

The main effect of DL is illustrated in Figure 21. ST decreased as DL increased. Table 11 lists the result of a Newman-Keuls test. DL-1 resulted in significantly slower STs than DL-2 or DL-3.

Results of this analysis indicated that the effect of nonuniformities on search time is negligible. Subjects were able to perform the task with little interruption in search time performance. The nonuniformities altered the appearance of a background to the task information rather than causing an interference in the acquisition of task information. Only two effects appeared consistent. An interaction among G, DL, and DIM indicated that the SQ and TRI waves were more degrading to ST performance than the SINE wave. A possible explanation may be that because the modulations of the SQ and TRI wave fundamentals are higher than the SINE; thus, they are more distracting to subjects. A contributing factor is probably the visible "edges" of these waveforms at lower spatial frequencies (Appendix A). The effect of DL was also consistent. DL-1 resulted in slower search times.

Correct responses. An analysis of variance (ANOVA) on the percentage of correct responses (CR) was performed and the results are listed in Table 12. The DL x DIM interaction

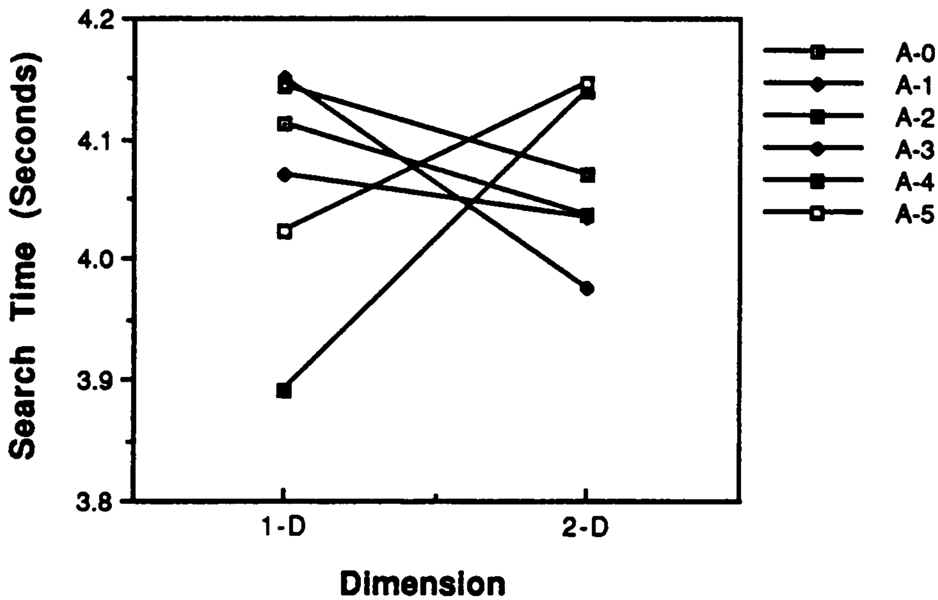


Figure 20. The A x DIM interaction for search time.

TABLE 10

Simple-Effect F-tests for DIM at Each Amplitude - Search Time

Source of Variance	df	MS	F	p
DIM at Amplitude 0	1	9192.07	0.56	0.4572
DIM at Amplitude 1	1	48444.25	2.94	0.0916
DIM at Amplitude 2	1	8899.59	0.54	0.4653
DIM at Amplitude 3	1	1914.40	0.11	0.7413
DIM at Amplitude 4	1	96134.28	5.84	0.0187
DIM at Amplitude 5	1	24118.72	1.46	0.2317
A x DIM x S/G	60	16470.07		

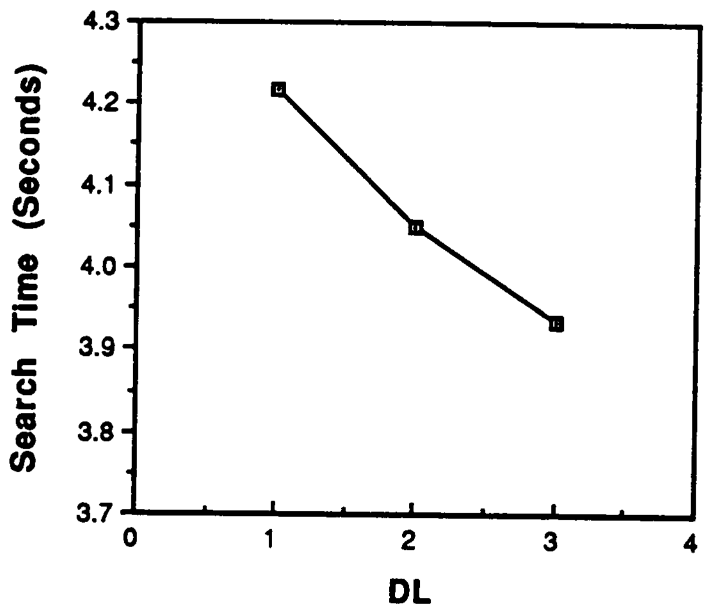


Figure 21. The effect of DL on search time.

TABLE 11

Newman-Keuls Comparisons for Display Luminance - Search Time

Display Luminance	Mean ST (s)		(s)
0	4.22	A	
1	4.05		B
2	3.93		B

Note: Means accompanied by the same letter are not significantly different, $p \geq .05$

TABLE 12

Analysis of Variance Summary Table for Correct Responses

Source of Variance	df	MS	F	p
Between Subjects				
Gradient (G)	2	0.1298	0.71	0.5108
Subjects within Gradient (S/G)	12	0.1826		
Within Subjects				
Frequency (F)	6	0.0123	2.10	0.0636
F*G	12	0.0047	0.81	0.6393
F*(S/G)	72	0.0059		
Amplitude (A)	5	0.0054	0.95	0.4571
A*G	10	0.0020	0.34	0.9648
A*(S/G)	60	0.0057		
DL	2	0.0200	2.61	0.0941
DL*G	4	0.0002	0.03	0.9981
DL*(S/G)	24	0.0077		
Dimension (DIM)	1	0.0018	0.43	0.5236
DIM*G	2	0.0013	0.32	0.7344
DIM*(S/G)	12	0.0041		
F*DL	12	0.0058	1.38	0.1836
F*DL*G	24	0.0031	0.72	0.8202
F*DL*(S/G)	144	0.0042		
F*A	30	0.0049	0.98	0.5038
F*A*G	60	0.0062	1.23	0.1307
F*A*(S/G)	360	0.0051		
F*DIM	6	0.0039	0.82	0.5607
F*DIM*G	12	0.0060	1.25	0.2671
F*DIM*(S/G)	72	0.0048		

TABLE 12 (CONT)

Source of Variance	df	MS	F	p
A*DL	10	0.0032	0.69	0.7339
A*DL*G	20	0.0048	1.03	0.4368
A*DL*(S/G)	120	0.0047		
A*DIM	5	0.0079	1.43	0.2279
A*DIM*G	10	0.0035	0.63	0.7821
A*DIM*(S/G)	60	0.0055		
DL*DIM	2	0.0156	3.05	0.0659
DL*DIM*G	4	0.0059	1.16	0.3549
DL*DIM*(S/G)	24	0.0051		
F*A*DL	60	0.0050	0.90	0.6860
F*A*DL*G	120	0.0062	1.13	0.1803
F*A*DL*(S/G)	720	0.0055		
F*A*DIM	30	0.0062	1.25	0.1768
F*A*DIM*G	60	0.0059	1.19	0.1709
F*A*DIM*(S/G)	360	0.0050		
A*DL*DIM	10	0.0058	1.16	0.3279
A*DL*DIM*G	20	0.0046	0.92	0.5650
A*DL*DIM*(S/G)	120	0.0050		
DL*DIM*F	12	0.0056	1.05	0.4073
DL*DIM*F*G	24	0.0056	1.05	0.4072
DL*DIM*F*(S/G)	144	0.0053		
F*A*DL*DIM	60	0.0051	0.97	0.5407
F*A*DL*DIM*G	120	0.0050	0.95	0.6271
F*A*DL*DIM*(S/G)	720	0.0053		
Total	3779			

($p = 0.0659$) is illustrated in Figure 22. F-tests by DIM were performed and the results are in Table 13. No significant differences between DIMs were obtained, as might be expected from the p-value of the DL x DIM interaction.

The main effects of DL ($p = 0.0941$) and F ($p = 0.0636$) are illustrated in Figures 23 and 24, respectively. As DL increased, the mean CR increased and the increase in performance is consistent with ST data. The effect of F indicated a dip in CRs at 32 c/dw; however, the nature of this function is not meaningful. Since both effects have somewhat high p-values and show very small percent correct response differences, they should probably be ignored.

CR was not expected to be a highly sensitive measure because subjects were asked to search until they found the target; therefore, few errors were made.

Target confusion. The symbols used in this study were U.S. Army symbols which were originally designed for hard copy. Many of the symbols were very similar, with single lines or dots used to represent the differences among the symbols. Therefore, errors may not have been a function of the nonuniformities, but of confusion among symbols. Errors were analyzed in terms of confusion among symbols. If the errors were due to the introduction of nonuniformities the confusions should be random. Table 14 shows the target confusion matrix. It is obvious that certain symbols were confused with other symbols consistently. Redesign of these symbols is recommended if they are to be used for specific applications.

Random Search Conclusions

Nonuniformities were found to not significantly impact random search performance. Subjects were able to perform the task with no degradation even with the added nonuniformities. The lack of performance differences may be explained by several factors. First of all, the luminances of the nonuniformities were added to the symbol luminances; therefore, the symbol/

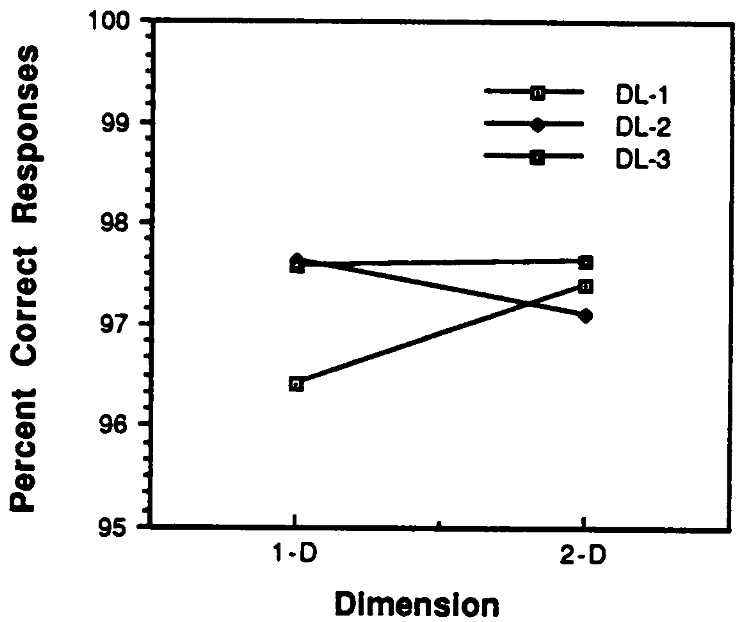


Figure 22. The DL x DIM interaction for percentage of correct responses.

TABLE 13

Simple-Effect F-tests for DIM at Each Display Luminance - Correct Responses

Source of Variance	df	MS	F	p
DIM for Display Luminance 1	1	0.0249	1.60	0.2180
DIM for Display Luminance 2	1	0.0081	0.52	0.4778
DIM for Display Luminance 3	1	0.00003	0.0019	0.9656
D x DIM x S/G	24	0.00156		

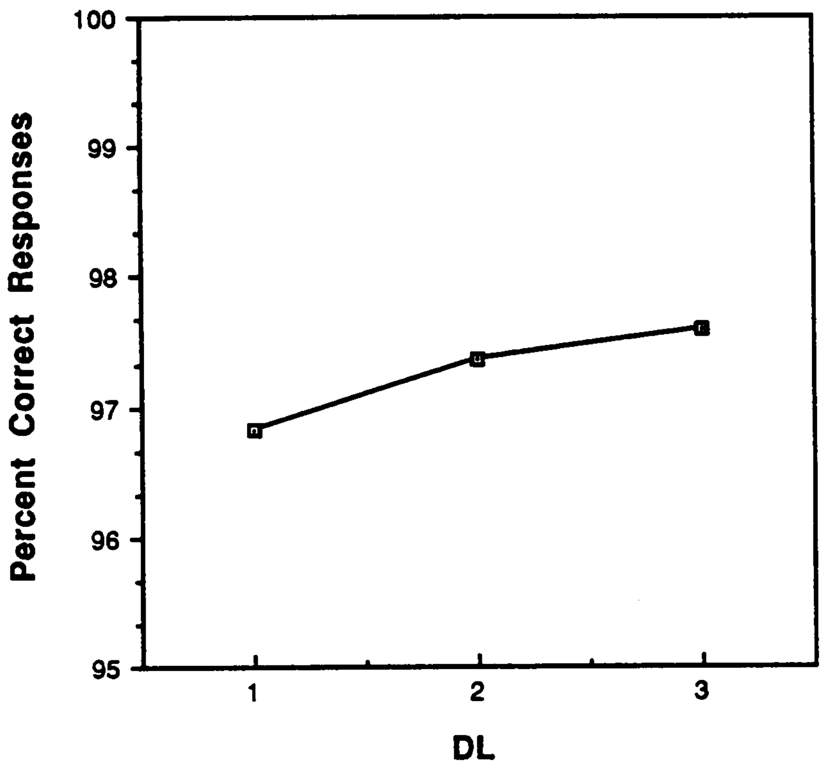


Figure 23. The effect of DL on percentage of correct responses.

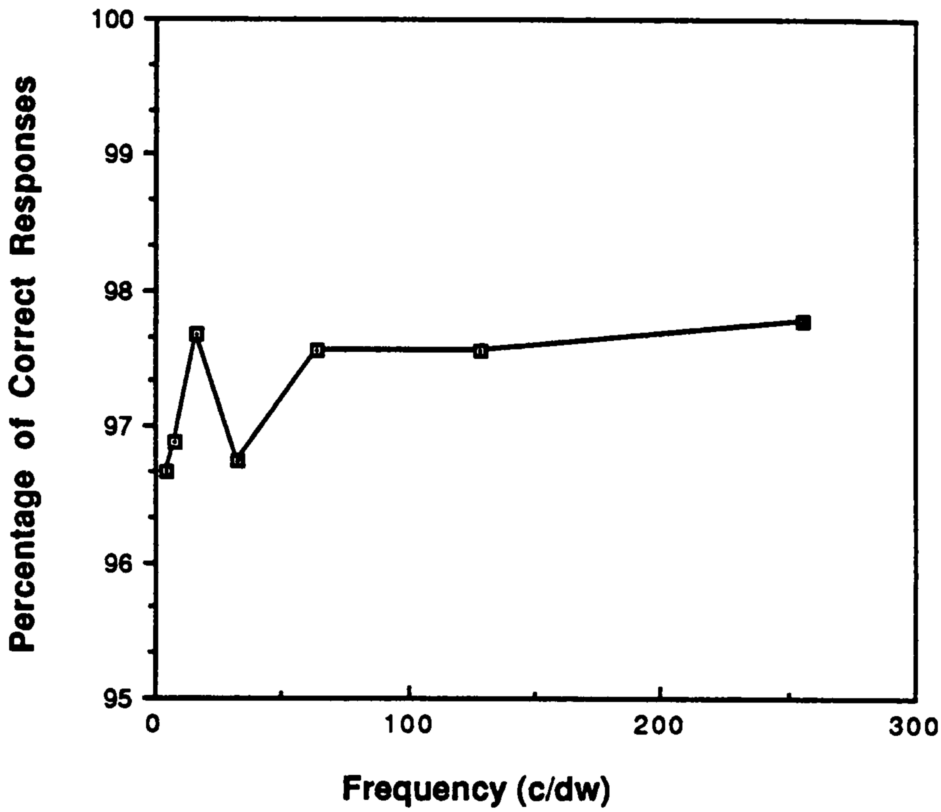


Figure 24. The effect of F on percentage of correct responses.

TABLE 14.

Symbol Confusion Matrix. Table Entries are Number of Incorrect Responses.

Target	Reponse 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	2	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0
2	9	0	0	4	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
3	2	0	0	7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	26	0	0
4	0	3	6	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
5	0	0	1	1	0	3	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
6	0	1	0	0	2	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
7	0	0	0	0	4	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	21
8	0	0	0	4	0	11	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
9	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	1	0	0	9	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0
11	0	0	0	0	0	0	0	0	0	0	0	26	2	1	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	1	0	0	0	0	0	0	10	0	0	3	1	1	0	0	0	1	0	1	0	1	0	0
13	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	3	1	0	0	0	0	0	0	0	1	0	12	0	0	0	0	0	0	0	1	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	12	2	1	0	0	0	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	1	0	0	1	22	0	1	8	0	0	0	0	0	0	1	0
17	0	0	0	0	0	0	0	1	0	0	1	0	0	0	4	2	0	9	0	0	0	0	0	0	0	0
18	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	9	19	0	0	1	0	0	1	1	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	6	1	0	1	0	0
20	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	1	10	0	1	11	0	1	0	0
21	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	2	0	7	0	0	12	0	0	0	0
22	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	2	18	4	0	0	0	0	0
23	8	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	3	0	0
24	0	0	27	1	0	1	5	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
25	0	0	0	14	5	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4
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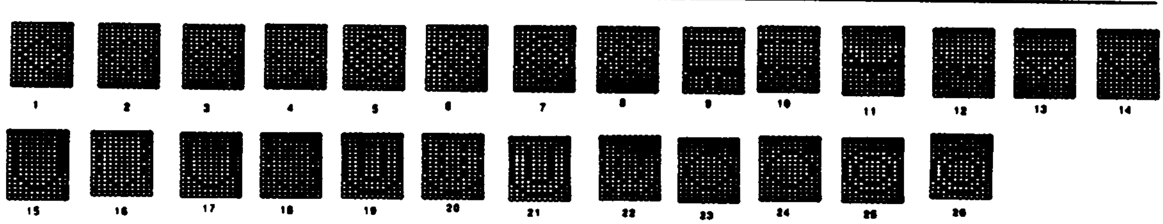


background modulations were always above recommended (e.g., ANSI, 1988) levels. That is, the nonuniformities did not degrade the symbol modulation. Also, the nonuniformities were systematic and had the appearance of a background to the map and symbols. Perhaps subjects were able to ignore the nonuniformities. If nonuniformities were random it may have been more difficult to visually separate the nonuniformities from the symbols.

Another possible explanation is that the nonuniformities, which can be considered as noise, were always at spatial frequencies below the spatial frequency of the targets and maps which were one pixel wide; therefore, masking effects did not occur.

Although subjects were able to perform the search task in the presence of nonuniformities, many subjects commented that the nonuniformities were annoying and fatiguing. Some subjects also commented that the SINE wave shapes were blurry. Long term performance with a display which exhibits nonuniformity levels used in this study may induce eye fatigue and strain over many hours.

Tasks which require extraction of information from a literal image where gray scale is used to present picture details (for example, a digitized picture) may be more sensitive to nonuniformities. In these tasks, the nonuniformities may not appear as a background, but as an interruption in the continuity of the image.

Magnitude Estimation Task

For this task the free-modulus technique was employed. The free-modulus technique allows subjects to select their own scale to describe the stimuli presented. The data are then transformed to place ratings of perceived uniformity on the same scale. The data were transformed using the method described by Kling and Riggs (1971); this method is presented in Appendix C. Before scaling, a constant of 101 was added to each rating of perceived uniformity for all subjects to bring the range into the positive domain. The range of the subject mean perceived uniformity scores was 11 to 301. These values were used in the analyses.

After scaling, two separate analysis of variance (ANOVA) procedures were performed. One analysis included the A-0 condition which was a baseline; that is, nonuniformities were not presented (other than those inherent in the display itself). The baseline was an important variable which gave an indication of how far from a uniform screen the subjects estimated the nonuniformities to be. It also served as a check to the reliability of subjects' perceptions. Subjects would be expected to rate the A-0 condition the same throughout the study. In addition, an analysis without the baseline was included because it was often difficult to determine whether significant effects were being unduly weighted by this A-0 condition. Results of both analyses are presented below.

Results with baseline. Results of the ANOVA are shown in Table 15. Results indicated a significant fourth-order interaction (F x A x DL x DIM), four significant third-order interactions (F x A x DL; F x A x G; F x G x DL, F x G x DIM), and six significant second-order interactions (F x A; F x DL; F x G; A x G; G x DL; A x DL). All main effects were significant and will be discussed in the context of the interactions to avoid redundancy. Post-hoc simple-effect F-tests and Newman-Keuls comparison tests were conducted to further evaluate significant effects.

The F x A x DL x DIM interaction is illustrated in Figure 25. This interaction is divided into three three-way interactions for presentation. Note that large values of perceived uniformity indicate that subjects rated the condition as being more uniform in luminance. Simple-effect F-tests were conducted on each variable and are listed in Tables 16 through 19.

The A x DL x DIM interaction is significant for the 128 c/dw condition only. In Figure 25, comparing the 1- and 2-D conditions at DL-1 and DL-2, the ranges in perceived uniformity across

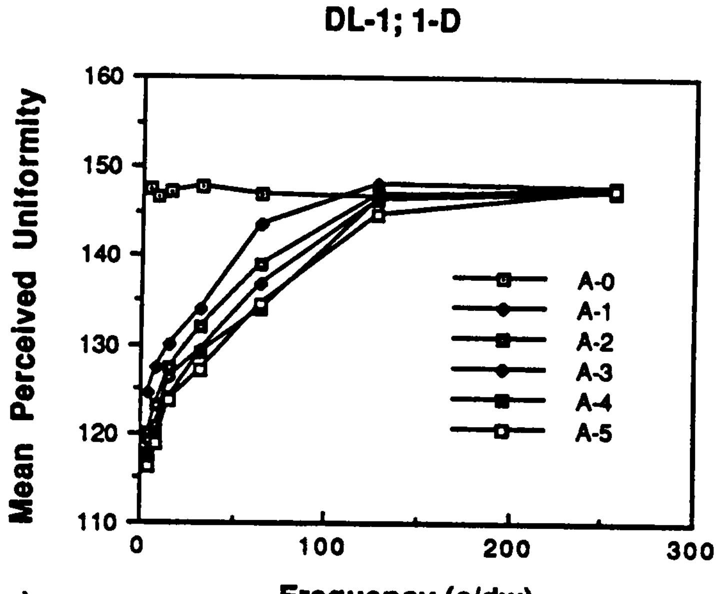
TABLE 15

Analysis of Variance Summary Table for Magnitude Estimation, Baseline Included

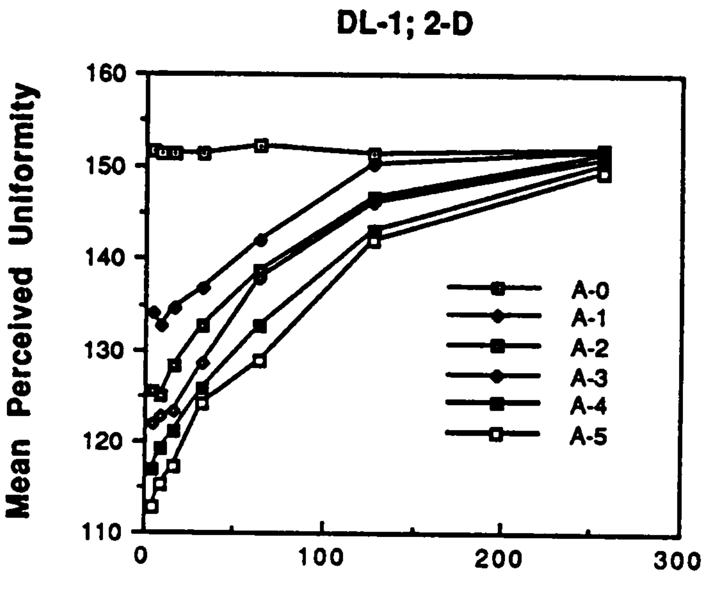
Source of Variance	df	MS	F	p
Between Subjects				
Dimension (DIM)	1	1635.74	0.27	0.6098
Subjects within Dimension (S/DIM)	28	6138.68		
Within Subjects				
Frequency (F)	6	131604.13	20.65	0.0001
F*DIM	6	977.33	0.15	0.9882
F*(S/DIM)	168	6373.91		
Amplitude (A)	5	157289.88	23.78	0.0001
A*DIM	5	395.01	0.60	0.7011
A*(S/DIM))	140	6613.07		
Display Luminance (DL)	2	24568.34	23.68	0.0001
DL*DIM	2	133.77	0.13	0.8793
DL*(S/DIM)	56	1037.70		
G	2	18723.40	11.42	0.0001
G*DIM	2	3518.10	2.15	0.1266
G*(S/DIM)	56	1640.00		
F*DL	12	1057.84	7.60	0.0001
F*DL*DIM	12	73.35	0.53	0.8971
F*DL*(S/DIM)	336	139.33		
F*A	30	5774.28	17.07	0.0001
F*A*DIM	30	272.26	0.80	0.7632
F*A*(S/DIM)	840	338.36		
F*G	12	1776.56	7.72	0.0001
F*G*DIM	12	394.55	1.71	0.0624
F*G*(S/DIM)	336	230.24		

TABLE 15 (CONT)

Source of Variance	df	MS	F	p
A*DL	10	1714.34	17.76	0.0001
A*DL*DIM	10	34.03	0.35	0.9653
A*DL*(S/DIM)	280	96.52		
A*G	10	827.41	7.44	0.0001
A*G*DIM	10	161.81	1.46	0.1557
A*G*(S/DIM))	280	111.14		
DL*G	4	464.07	6.30	0.0001
DL*G*DIM	4	51.28	0.70	0.5964
DL*G*(S/DIM)	112	73.71		
F*A*DL	60	70.34	21.4	0.0001
F*A*DL*DIM	60	47.68	1.45	0.0151
F*A*DL*(S/DIM)	1680	32.92		
F*A*G	60	116.10	3.33	0.0001
F*A*G*DIM	60	41.68	1.19	0.1497
F*A*G*(S/DIM)	1680	34.90		
A*DL*G	20	32.73	1.31	0.1639
A*DL*G*DIM	20	20.21	0.81	0.7023
A*DL*G*(S/DIM)	560	24.94		
DL*G*F	24	50.54	1.75	0.0153
DL*G*F*DIM	24	29.26	1.01	0.4478
DL*G*F*(S/DIM)	672	28.92		
F*A*DL*G	120	24.34	1.06	0.3080
F*A*DL*G*DIM	120	26.38	1.15	0.1285
F*A*DL*G*(S/DIM)	3360	22.93		
Total	11339			

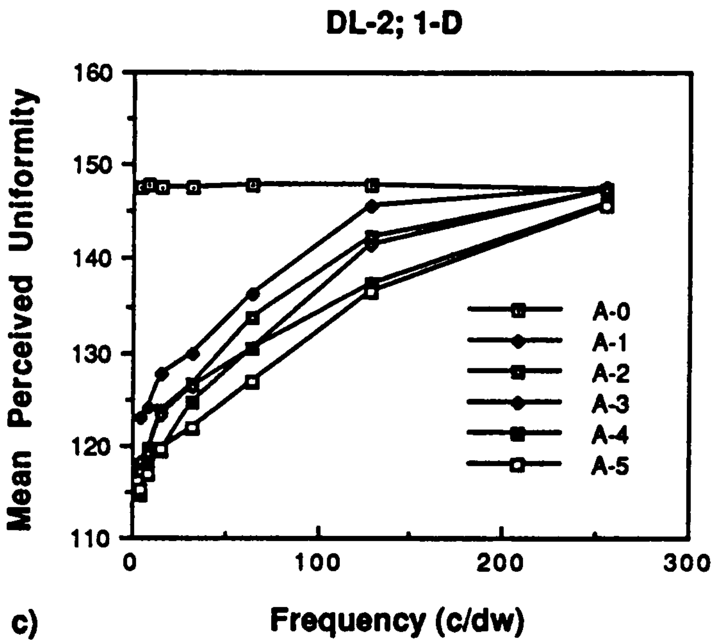


a)

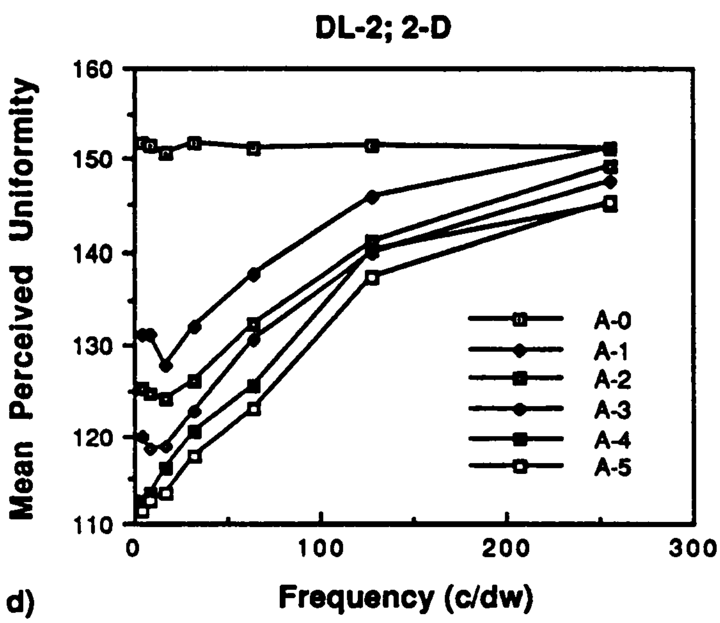


b)

Figure 25. The F x A x DL x DIM interaction for mean perceived uniformity. a) DL-1, 1-D b) DL-1, 2-D c) DL-2, 1-D d) DL-2, 2-D e) DL-3, 1-D f) DL-3, 2-D.

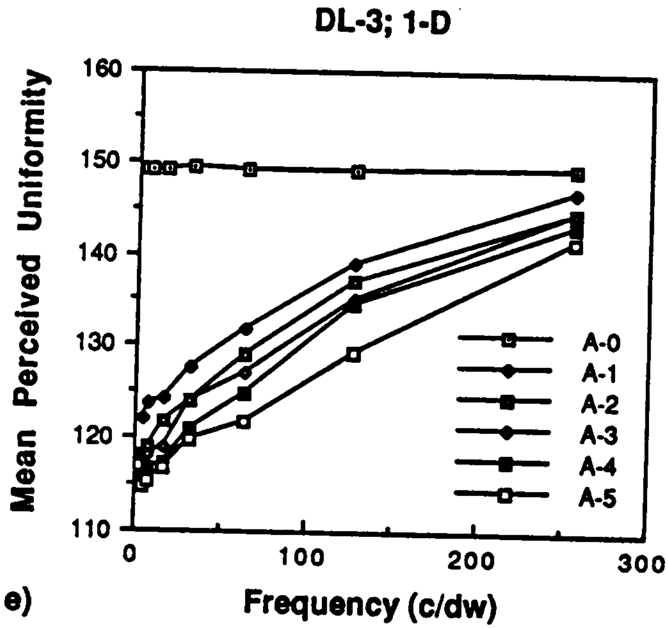


c)

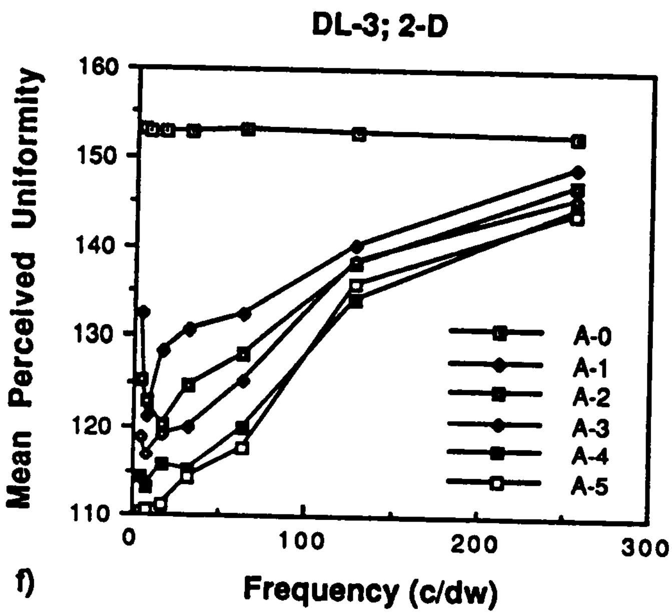


d)

Figure 25 cont.



e)



f)

Figure 25 cont.

TABLE 16

Simple-Effect F-tests for A x DL x DIM at Each Frequency - Magnitude Estimation

Source of Variance	df	MS	F	p
A x DL x DIM for 4 cycles/display	10	17.03	0.52	0.8771
A x DL x DIM for 8 cycles/display	10	49.39	1.50	0.1332
A x DL x DIM for 16 cycles/display	10	40.31	1.22	0.2729
A x DL x DIM for 32 cycles/display	10	16.54	0.50	0.8909
A x DL x DIM for 64 cycles/display	10	46.52	1.41	0.1696
A x DL x DIM for 128 cycles/display	10	127.31	3.87	0.0003
A x DL x DIM for 250 cycles/display	10	22.98	0.70	0.7271
A x DL x F x (S/DIM)	1680	32.92		

TABLE 17

Simple-Effect F-tests for F x DL x DIM at Each Amplitude - Magnitude Estimation

Source of Variance	df	MS	F	p
F x DLx DIM for Amplitude 0	12	5.44	0.16	0.9951
F x DL x DIM for Amplitude 1	12	44.51	1.35	0.1836
F x DL x DIM for Amplitude 2	12	34.16	1.04	0.4086
F x DL x DIM for Amplitude 3	12	62.93	1.91	0.0292
F x DL x DIM for Amplitude 4	12	75.76	2.29	0.0069
F x DL x DIM for Amplitude 5	12	90.32	2.74	0.0011
F x DL x A x S/DIM	1680	32.92		

TABLE 18

Simple-Effect F-tests for F x A x DIM at Each Display Luminance - Magnitude Estimation

Source of Variance	df	MS	F	p
F x A x DIM for DL- 1	30	81.53	2.48	< 0.0001
F x A x DIM for DL -2	30	118.07	3.59	< 0.0001
F x A x DIM for DL -3	30	168.01	5.10	< 0.0001
F x A x DL x S/DIM	1680	32.92		

TABLE 19

Simple-Effect F-tests for F x A x DL for One and Two Dimensions - Magnitude Estimation

Source of Variance	df	MS	F	p
F x A x DL for 1-D	60	59.50	1.81	0.0002
F x A x DL for 2-D	60	58.51	1.78	0.0003
F x A x DL x S/DIM	1680	32.92		

the different levels of A (at 128 c/dw) are smaller for the 1-D condition. This difference in range is not apparent at DL-3. As previously discussed, the DL levels for the 2-D condition are higher than those for the 1-D condition and may be contributing to this effect. Results of the F x DL x DIM tests by A, listed in Table 17, indicate that this interaction is significant for A-3, A-4, and A-5. The F-tests by DL and DIM indicate that all interactions are significant for these variables. Therefore, these tests add little to describing the effect.

In general, the fourth-order effect described above indicates the following general trends in the data.

(1) As F increased, perceived uniformity increased; that is, subjects reported that the display appeared more uniform, irrespective of levels of DIM and A.

(2) As A increased, perceived uniformity decreased.

(3) As DL increased, perceived uniformity decreased.

(4) At A-0, no differences existed, thus proving the constancy of the "control" condition.

The F x A x DL interaction is illustrated in Figure 26 and is represented as three two-way interactions. F-tests by DL are presented in Table 20. Results indicated that the F x A interaction was significant at each level of DL. F-tests by A are presented in Table 21. The F x DL interaction was significant for all but the baseline condition, indicating that the baseline may be causing this triple interaction to reach significance. This issue is explored in the next analysis. Results of the interaction are the same as those for the four-way interaction discussed previously; that is, as F increases perceived uniformity increases and as A and DL increases perceived uniformity decreases.

Figure 27 illustrates the F x A x G interaction and is presented as three two-way interactions. Results of F-tests at each A are listed in Table 22. The F x G interaction was

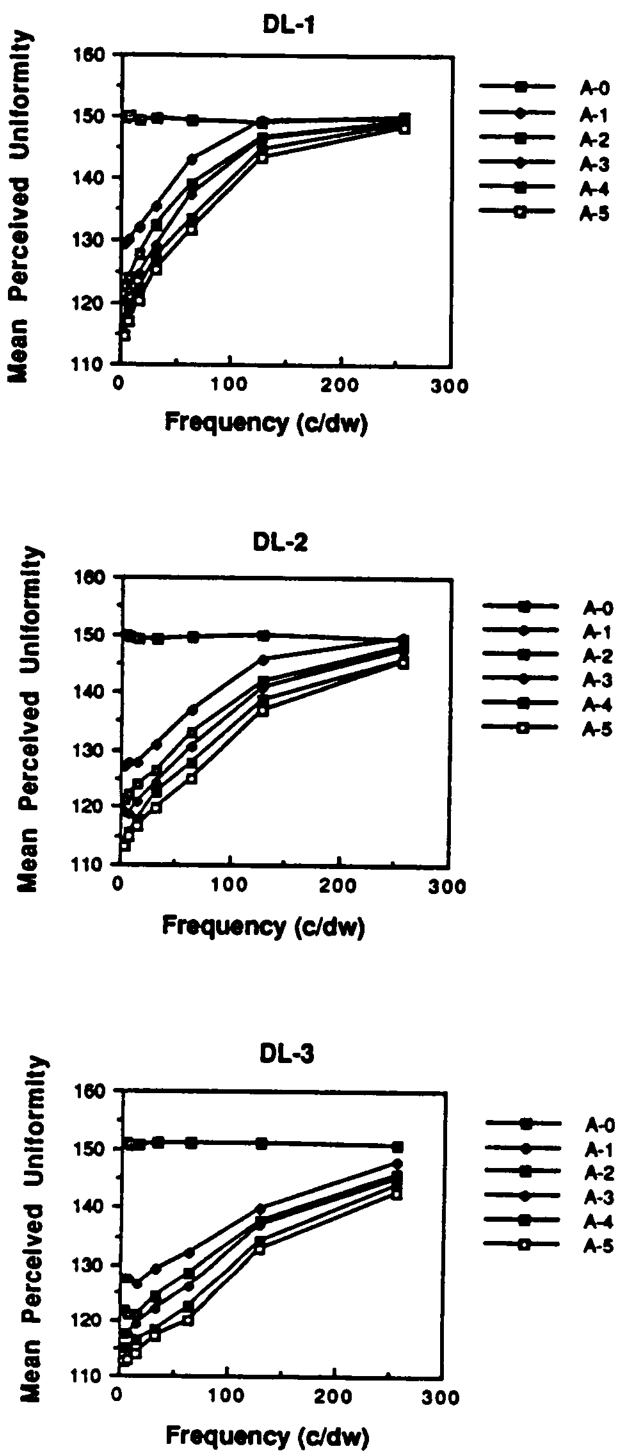


Figure 26. The F x A x DL interaction for mean perceived uniformity.

TABLE 20

Simple-Effect F-tests for F x A at Each DL - Magnitude Estimation

Source of Variance	df	MS	F	p
F x A for DL-1	30	2148.04	65.25	< 0.0001
F x A for DL-2	30	1996.52	60.65	< 0.0001
F x A for DL-3	30	177041.00	53.78	< 0.0001
F x A x DL x S/DIM	1680	32.92		

TABLE 21

Simple-Effect F-tests for F x DL at Each Amplitude - Magnitude Estimation

Source of Variance	df	MS	F	p
F x DL for Amplitude 0	12	5.44	0.16	0.9995
F x DL for Amplitude 1	12	328.65	9.98	<0.0001
F x DL for Amplitude 2	12	302.74	9.20	<0.0001
F x DL for Amplitude 3	12	210.71	6.40	<0.0001
F x DL for Amplitude 4	12	274.79	8.35	<0.0001
F x DL for Amplitude 5	12	287.22	8.73	<0.0001
F x DL x A x S/DIM	1680	32.92		

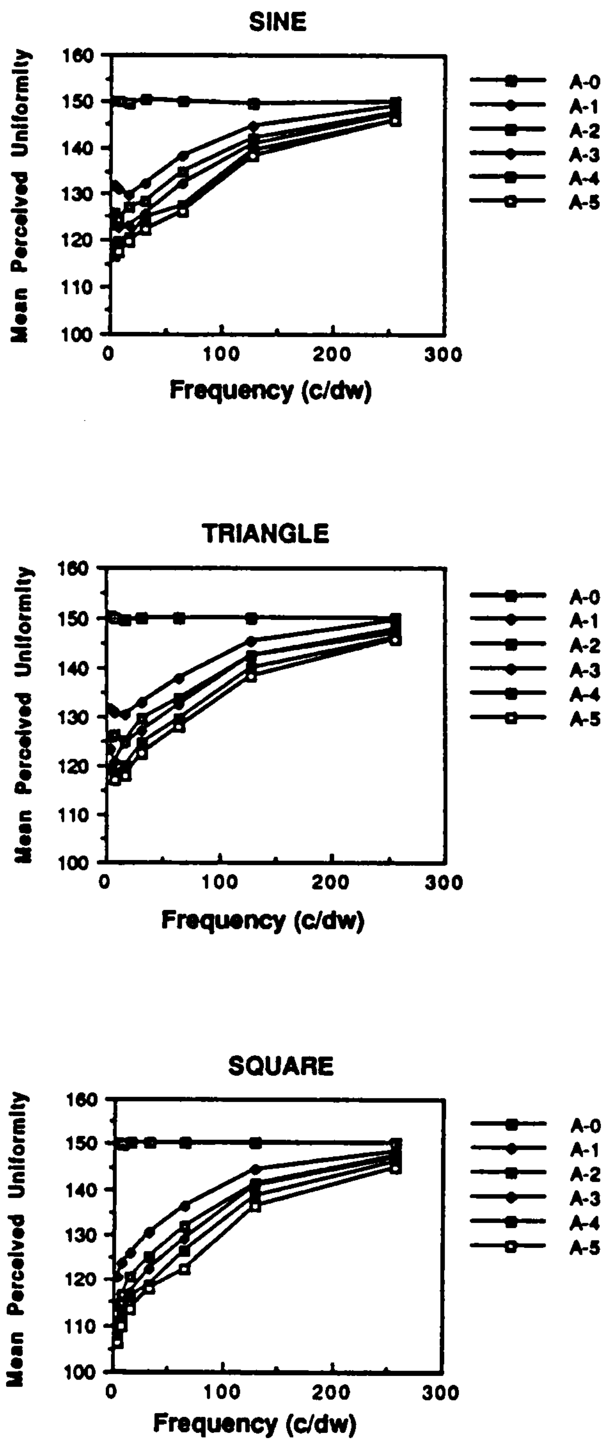


Figure 27. The F x A x G interaction for mean perceived uniformity.

TABLE 22

Simple-Effect F-tests for F x G at Each Amplitude - Magnitude Estimation

Source of Variance	df	MS	F	p
F x G for Amplitude 0	12	3.68	0.11	0.9999
F x G for Amplitude 1	12	471.42	13.51	< 0.0001
F x G for Amplitude 2	12	520.65	14.92	< 0.0001
F x G for Amplitude 3	12	582.20	16.68	< 0.0001
F x G for Amplitude 4	12	439.78	12.60	< 0.0001
F x G for Amplitude 5	12	339.36	9.72	< 0.0001
F x G x A x S/DIM	1680	34.90		

significant at all A levels except the baseline condition. Table 23 lists the results of F-tests across F. The A x G interaction was significant at all but the two highest F levels, 128 and 256 c/dw. Perceived uniformity was lower for the SQ wave than for the SINE and TRI wave conditions. Also, the range in perceived uniformity across A and F appears larger for the SQ condition. These results are consistent with the research findings of De Palma and Lowry (1962), who reported that lower modulations were required to detect square waves at lower spatial frequencies because of the higher amplitude of the fundamental frequency and because the harmonics of the square wave contribute to detection when spatial frequencies are low. As spatial frequency increases even higher levels of modulation are required for detection of the fundamental and harmonics. The modulations of the harmonics are not high enough to contribute to detection in the 128 and 256 c/dw condition, as shown in Appendix A. At the higher spatial frequencies, the curves converge simply because there is no appreciable visual discrimination across the G or A variables.

Figure 28 illustrates the F x G X DL interaction which is presented as three two-way effects. Simple-effect F-test results across F levels are listed in Table 24. The G x DL interaction is not significant for the 128 and 256 c/dw conditions, which is consistent with the results discussed above for the F x A x G interaction. Perceived uniformity is lower for the SQ wave at the lower spatial frequencies. Perceived uniformity ratings for the SINE and TRI wave shapes are very similar. The trends for F and DL are consistent with previous findings: as F increases perceived uniformity increases and as DL increases perceived uniformity decrease.

Figure 29 illustrates the F x G x DIM ($p = 0.0624$), interaction presented as two second-order effects. Simple-effect F-test results for the G x DIM contributions are listed in Table 25. The G x DIM interaction is significant for 4, 8, and 16 c/dw. Perceived uniformity was lower for the 2-D SQ wave at each of these F levels.

TABLE 23

Simple-Effect F-tests for A x G at Each Frequency - Magnitude Estimation

Source of Variance	df	MS	F	p
A x G for 4 cycles/display	10	675.66	19.36	< 0.0001
A x G for 8 cycles/display	10	341.83	9.79	< 0.0001
A x G for 16 cycles/display	10	236.29	6.77	< 0.0001
A x G for 32 cycles/display	10	126.02	3.61	< 0.0001
A x G for 64 cycles/display	10	108.75	3.12	0.0006
A x G for 128 cycles/display	10	26.75	0.77	0.6580
A x G for 256 cycles/display	10	8.73	0.25	0.9908
A x G x F x S/DIM	1680	34.90		

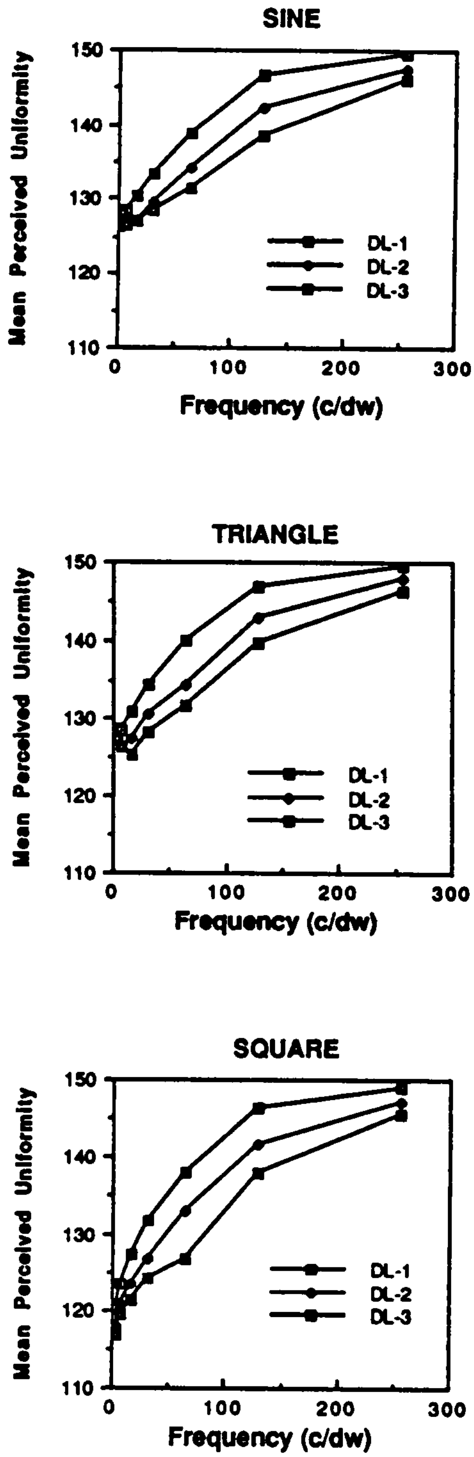


Figure 28. The F x G x DL interaction for mean perceived uniformity.

TABLE 24

Simple-Effect F-tests for G x DL at Each Frequency - Magnitude Estimation

Source of Variance	df	MS	F	p
G x DL for 4 cycles/display	4	168.98	5.84	<0.0001
G x DL for 8 cycles/display	4	69.27	2.39	0.0496
G x DL for 16 cycles/display	4	128.65	4.45	0.0015
G x DL for 32 cycles/display	4	92.22	3.19	0.0131
G x DL for 64 cycles/display	4	278.15	9.62	< 0.0001
G x DL for 128 cycles/display	4	27.29	0.94	0.4402
G x DL for 256 cycles/display	4	2.72	0.09	0.9856
G x DL x F x S/DIM	672	28.92		

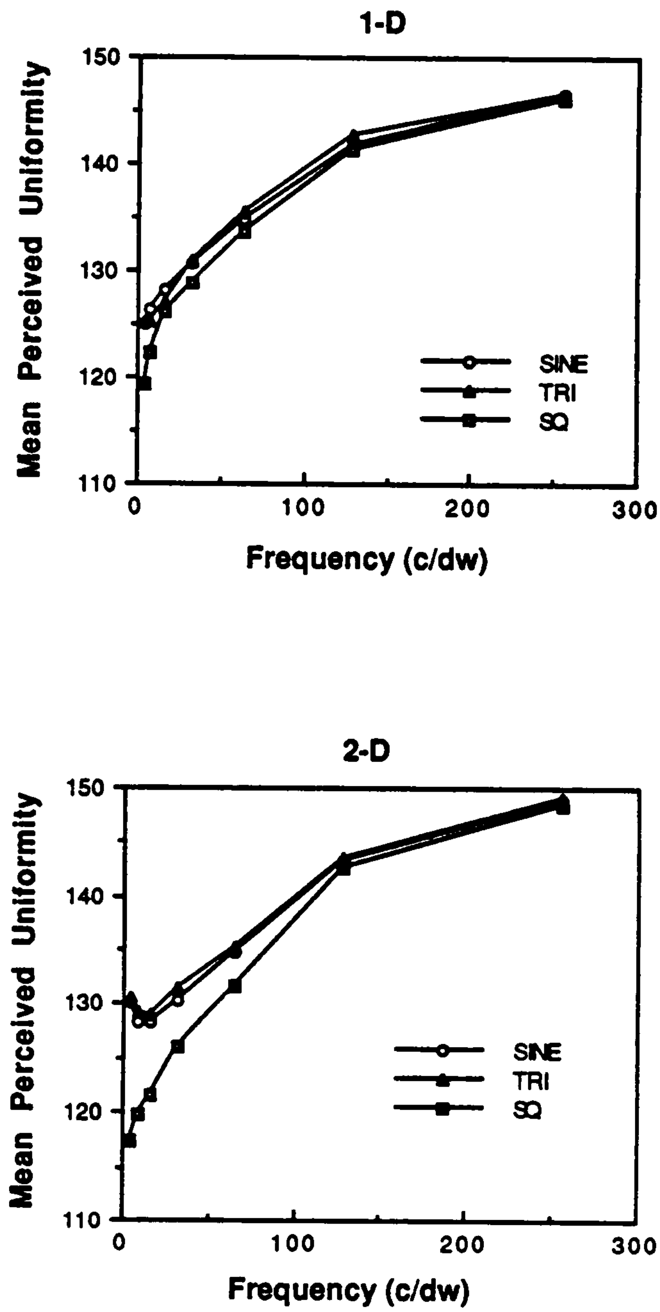


Figure 29. The F x G x DIM interaction for mean perceived uniformity.

TABLE 25

Simple-Effect F-tests for G x DIM at Each Frequency - Magnitude Estimation

Source of Variance	df	MS	F	p
G x DIM for 4 cycles/display	2	2474.92	10.75	0.0003
G x DIM for 8 cycles/display	2	1480.81	6.43	0.0018
G x DIM for 16 cycles/display	2	1400.21	6.08	0.0025
G x DIM for 32 cycles/display	2	361.93	1.57	0.2096
G x DIM for 64 cycles/display	2	151.02	0.66	0.5175
G x DIM for 128 cycles/display	2	13.07	0.06	0.9417
G x DIM for 256 cycles/display	2	3.42	0.01	0.9900
G x F x S/DIM	336	230.24		

Results of an F-test of F x G at each DIM are listed in Table 26. A significant F x G interaction was found for the 2-D condition, indicating that there were no differences in perceived uniformity for G shapes as a function of F for 1-D conditions. As illustrated in Figure 29, these three G functions are very similar and parallel.

Table 27 lists results for F-tests of the F x DIM interaction, which is significant for each wave shape. Perceived uniformity is lower for the 2-D wave shapes across F levels 4 - 64 c/dw, with the largest difference occurring for the SQ wave. The differences in 1- and 2-D perceived uniformity is very possibly an effect of DL differences, as described earlier.

Analysis of the second-order effects shows that the data trends are consistent. The F x A interaction is significant and is illustrated in Figure 30. A Newman-Keuls comparison test was performed on the A means at each F level and results are listed in Table 28. As A increases, perceived uniformity decreases. As F increases, the curves converge and the number of significant differences among A levels decreases. At 256 c/dw, there are no significant differences in perceived uniformity as a function of A. At this level, subjects rated all A levels as appearing the same in terms of their perceived uniformity. The modulations passed by the display at this F are not high enough for subjects to determine differences among the A conditions, as shown in Appendix A.

Figure 31 illustrates the F x DL interaction. There is a significant effect of DL at all F levels except 4 c/dw. Newman-Keuls test results on the DL means at each F are reported in Table 29. Perceived uniformity at all three DL levels are significantly different from one another at all F levels except 4 c/dw. As DL increases, perceived uniformity significantly and consistently decreases. These results follow the shape of the CTF. The effect of DL is greater at the middle F levels. The effect of DL decreases as F increases or decreases.

TABLE 26

Simple-Effect F-tests for F x G for One and Two Dimensions - Magnitude Estimation

Source of Variance	df	MS	F	p
F x G for 1-D	12	345.29	1.50	0.1221
F x G for 2-D	12	1825.81	7.93	< 0.0001
G x F x S/DIM	336	230.24		

TABLE 27

Simple-Effect F-tests for F x DIM for each Gradient - Magnitude Estimation

Source of Variance	df	MS	F	p
F x DIM for SINE	6	507.63	2.20	0.0427
Fx DIM for SQ	6	548.90	2.38	0.0289
F x DIM for TRI	6	709.89	3.08	0.0060
G x F x S/DIM	336	230.24		

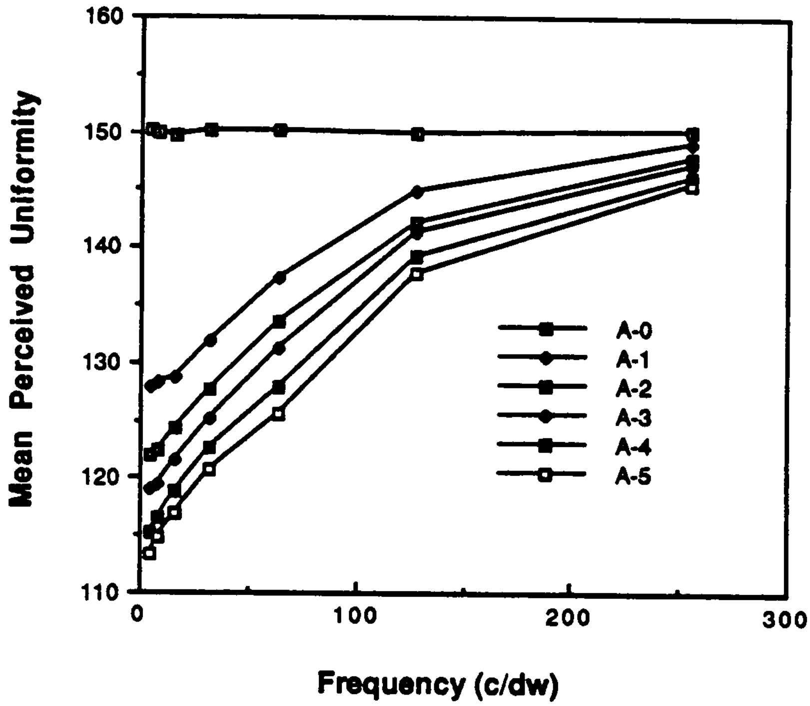


Figure 30. The F x A interaction for mean perceived uniformity.

TABLE 28

Newman-Keuls Comparisons for A at Each Frequency- Magnitude Estimation

	4 cycles/display	8 cycles/display	16 cycles/display	32 cycles/display
Amplitude	MPU	MPU	MPU	MPU
0	150.18 A	149.85 A	149.77 A	150.17 A
1	127.84 B	128.38 B	128.71 B	131.86 B
2	121.89 C	122.38 C	124.22 C	127.69 C
3	118.97 C	119.37 CD	121.55 CD	125.15 CD
4	115.30 D	116.60 DE	118.88 DE	122.67 DE
5	113.40 D	114.91 E	116.94 E	120.80 E

	64 cycles/display	128 cycles/display	256 cycles/display
Amplitude	MPU	MPU	MPU
0	150.08 A	149.94 A	150.04 A
1	137.36 B	144.86 B	149.02 A
2	133.49 C	142.05 BC	147.78 A
3	131.31 C	141.31 BCD	147.27 A
4	127.89 D	139.27 CD	146.11 A
5	125.51 D	137.63 D	145.57 A

MPU = mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

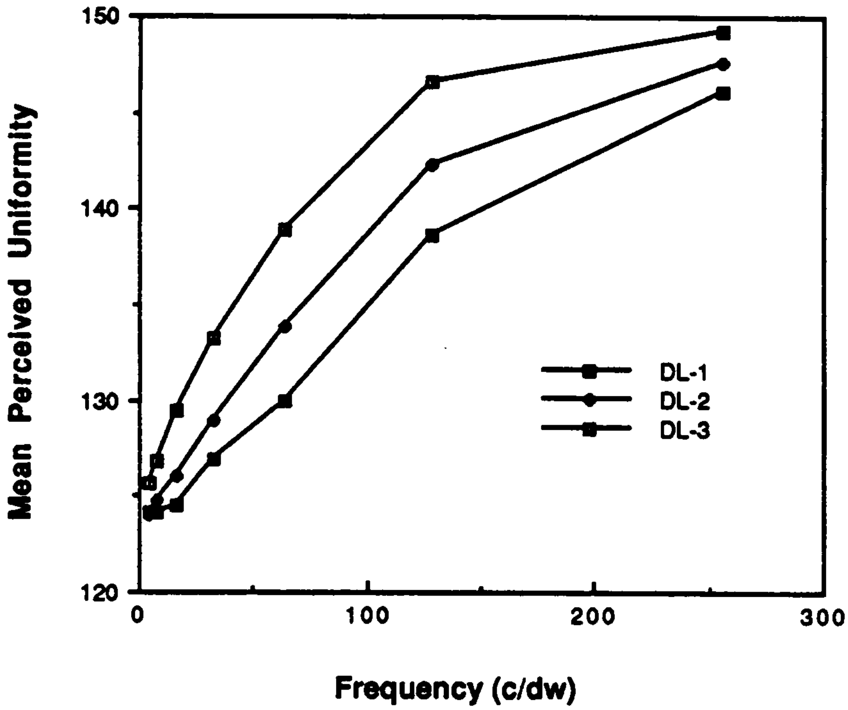


Figure 31. The F x DL interaction for mean perceived uniformity.

TABLE 29

Newman-Keuls Comparisons for DL at Each Frequency- Magnitude Estimation

	4 cycles/display			8 cycles/display			16 cycles/display			32 cycles/display	
DL	MPU		DL	MPU		DL	MPU		DL	MPU	
1	125.65	A	1	126.86	A	1	129.44	A	1	133.21	A
2	124.19	A	2	124.75	B	2	126.00	B	2	128.99	B
3	123.98	A	3	124.13	C	3	124.60	C	3	126.98	C

	64 cycles/display			128 cycles/display			256 cycles/display	
DL	MPU		DL	MPU		DL	MPU	
1	138.93	A	1	146.57	A	1	149.27	A
2	133.87	B	2	142.27	B	2	147.55	B
3	130.02	C	3	138.70	C	3	146.08	C

MPU = mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

Figure 32 illustrates the F x G interaction. Newman-Keuls comparisons for G at each F are listed in Table 30. Perceived uniformity was significantly lower for the SQ wave at all but the two highest F levels, 128 and 256 c/dw. Results are consistent with those previously discussed. That is, at the higher F levels the modulations are not high enough for subjects to determine differences among Gs.

The A x G interaction is presented in Figure 33. Results of the Newman-Keuls tests are listed in Table 31 and indicate that perceived uniformity was significantly lower for the SQ wave condition than either the SINE or TRI condition for all levels of A except the baseline condition, as should be the case. Less modulation is needed to detect the SQ wave, and the SQ wave is perceived as being more nonuniform than SINE or TRI waves. However, the interaction between A and G would not be significant if the baseline condition were not present. This will be discussed in the next section.

The G x DL interaction is shown in Figure 34. Newman-Keuls results for G at each DL are listed in Table 32. This effect also illustrates the differences among the SQ, SINE, and TRI waves. Again, the SQ wave results in significantly lower perceived uniformity ratings than the SINE or TRI wave. Overall, as DL increases, perceived uniformity consistently decreases; however, the effect that DL has on perceived uniformity is greater for SQ nonuniformities.

The A x DL interaction is shown in Figure 35. Newman-Keuls test results are presented in Table 33. Perceived uniformity was significantly different among all DLs at each A level other than A-0. It appears that this interaction reached significance because of the inclusion of the baseline condition. For the baseline condition, DL-3 resulted in significantly higher estimations. That is, subjects rated DL-3 as appearing more uniform than DL-1 or DL-2 when nonuniformities were not present, perhaps because the instructions stated that subjects were to rate how uniform in

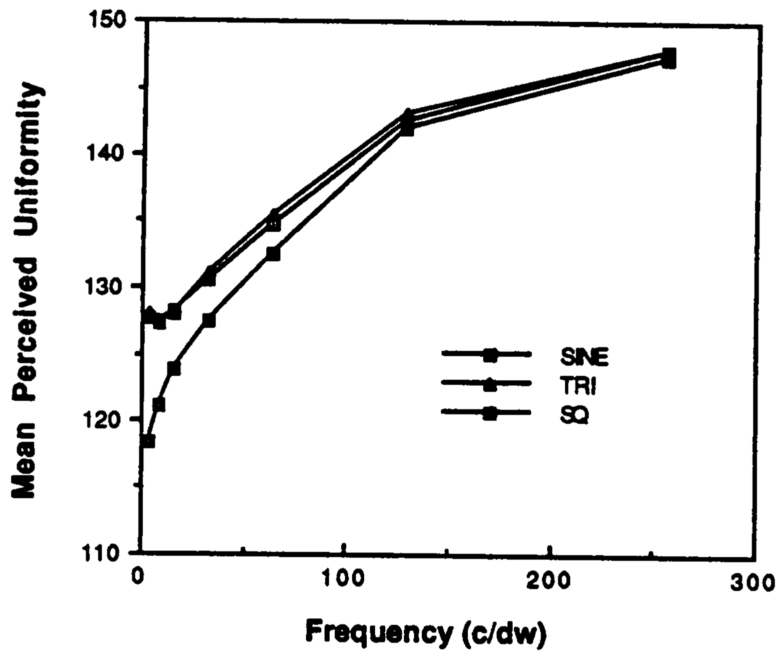


Figure 32. The F x G interaction for mean perceived uniformity.

TABLE 30

Newman-Keuls Comparisons for G at Each Frequency- Magnitude Estimation

4 cycles/display			8 cycles/display			16 cycles/display			32 cycles/display		
G	MPU		G	MPU		G	MPU				
TRI	127.92	A	SINE	127.43	A	SINE	128.17	A	TRI	131.13	A
SINE	127.55	A	TRI	127.20	A	TRI	127.97	A	SINE	130.57	A
SQ	118.35	B	SQ	121.12	B	SQ	123.90	B	SQ	127.47	B

64 cycles/display			128 cycles/display			256 cycles/display		
G	MPU		G	MPU		G	MPU	
TRI	135.39	A	TRI	143.09	A	TRI	147.86	A
SINE	134.81	A	SINE	142.50	A	SINE	147.74	A
SQ	132.62	B	SQ	141.95	A	SQ	147.30	A

MPU = mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

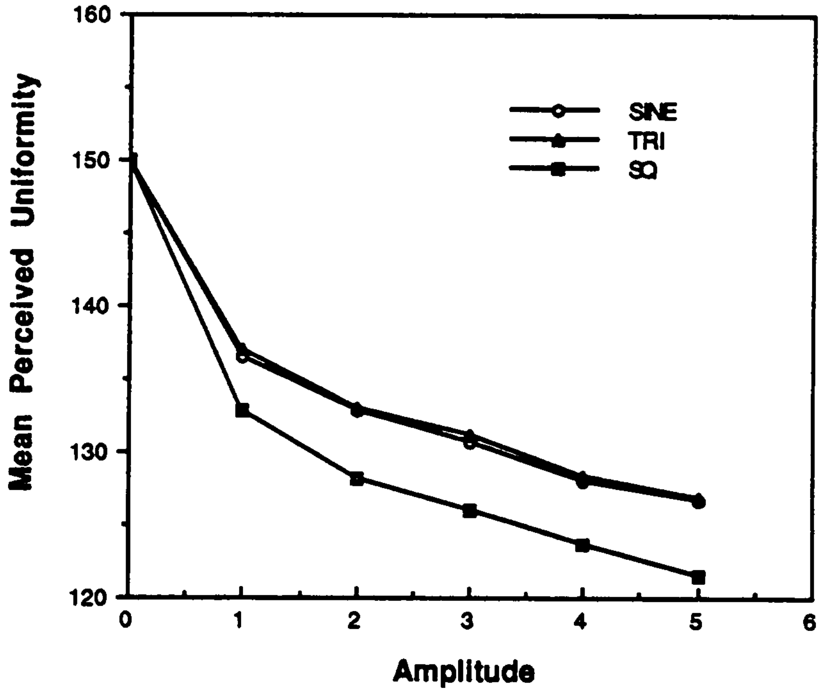


Figure 33. The A x G interaction for mean perceived uniformity.

TABLE 31

Newman-Keuls Comparisons for G at each Amplitude - Magnitude Estimation

Amplitude 0			Amplitude 1			Amplitude 2		
Gradient	MPU		Gradient	MPU		Gradient	MPU	
SQ	150.07	A	TRI	136.94	A	TRI	133.07	A
TRI	150.01	A	SINE	136.56	A	SINE	132.82	A
SINE	149.93	A	SQ	132.79	B	SQ	128.18	B

Amplitude 3			Amplitude 4			Amplitude 5		
Gradient	MPU		Gradient	MPU		Gradient	MPU	
TRI	131.13	A	TRI	128.25	A	TRI	126.78	A
SINE	130.68	A	SINE	128.02	A	SINE	126.63	A
SQ	126.01	B	SQ	123.75	B	SQ	121.51	B

MPU - mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

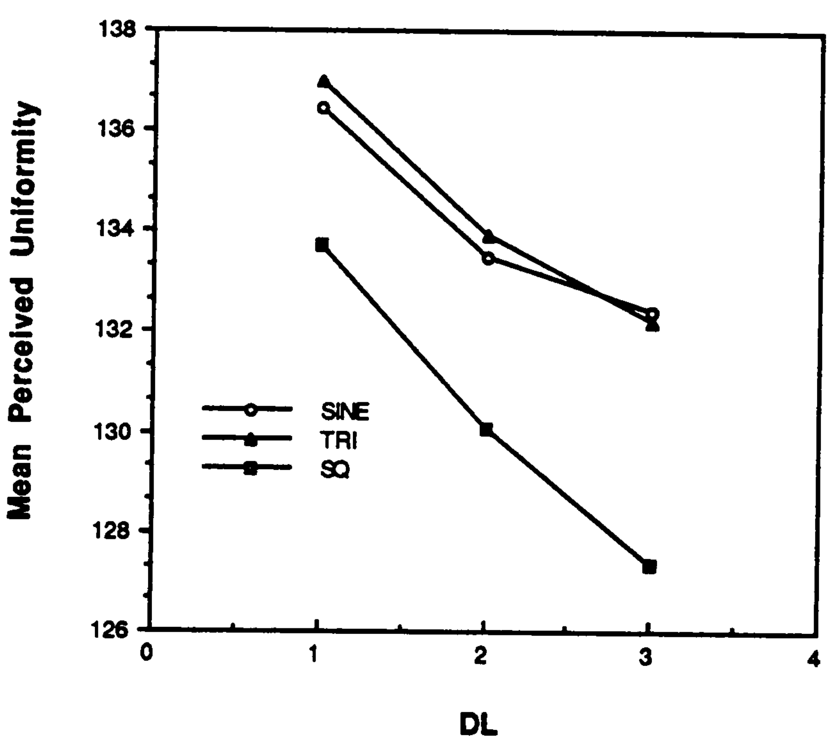


Figure 34. The G x DL interaction for mean perceived uniformity.

TABLE 32

Newman-Keuls Comparisons for G at each Display Luminance - Magnitude Estimation

Display Luminance 1		**Display Luminance 2**		**Display Luminance 3**	
Gradient	MPU	Gradient	MPU	Gradient	MPU
TRI	136.97 A	TRI	133.90 A	TRI	132.42 A
SINE	136.44 A	SINE	133.47 A	SINE	132.22 A
SQ	133.71 B	SQ	130.08 B	SQ	127.38 B

MPU - mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

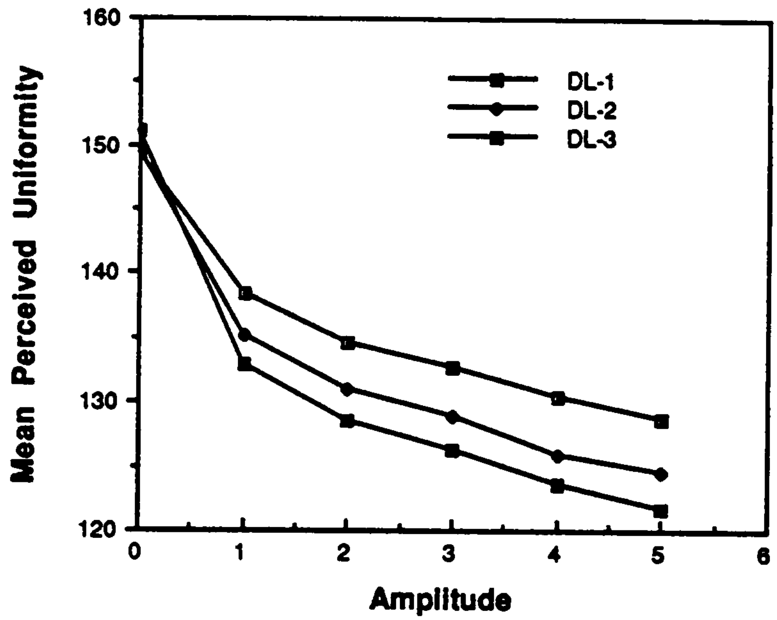


Figure 35. The A x DL interaction for mean perceived uniformity.

TABLE 33

Newman-Keuls Comparisons for DL at each Amplitude - Magnitude Estimation

Amplitude 0			Amplitude 1			Amplitude 2		
DL	MPU		DL	MPU		DL	MPU	
3	151.03	A	1	138.37	A	1	134.55	A
2	149.55	B	2	135.09	B	2	130.92	B
1	149.44	B	3	132.84	C	3	128.60	C

Amplitude 3			Amplitude 4			Amplitude 5		
DL	MPU		DL	MPU		DL	MPU	
1	132.67	A	1	130.49	A	1	128.70	A
2	128.85	B	2	125.95	B	2	124.55	B
3	126.32	C	3	123.58	C	3	121.67	C

MPU = mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

"luminance" the screen was. At lower DL levels they may not have detected "luminance," and so gave lower ratings.

Summary. The above analyses indicate very strong trends in the data and results are summarized below.

(1) As F increases, subjects report higher ratings of perceived uniformity; that is, they rate the screen as appearing more uniform in luminance.

(2) In general, as A increases perceived uniformity decreases. At the highest F level (256 c/dw), subjects' ratings of perceived uniformity are not significantly different among the A conditions. At this F, the ability of the display to pass modulation is limited by the MTF of the display. In addition, higher modulations are required for observers to detect higher frequencies. Both these factors contribute to the reduced perceptions of the nonuniformities.

(3) As DL increases perceived uniformity decreases; that is, subjects report that the patterns appear more nonuniform. At higher DL levels, less modulation is required for observers to detect gratings.

(4) The effect of DL also interacted with F and effects can be modelled after the CTF. The effect that DL has on perceived uniformity is greatest for the middle F levels, and decreases as F either increases or decreases.

(5) There are no significant differences in perceived uniformity between the SINE and TRI wave shapes. The SQ wave results in significantly lower ratings of perceived uniformity than the SINE or TRI waves. That is, subjects rate the SQ wave as appearing more nonuniform. However, the effect of the SQ wave on perceived uniformity is not significant at 128 and 256 c/dw. This finding is consistent with that of De Palma and Lowry (1962), who found that lower modulations are required to detect square waves at lower spatial frequencies. As previously discussed, this is a function of the higher amplitude of the fundamental frequency for the square wave and the contribution of the harmonics of the square wave. At higher spatial frequencies the harmonics are

at spatial frequencies that observers are unable to detect. Also, at these frequencies the display cannot pass the modulations required for detection.

(6) The effect of DIM is difficult to interpret because of the confound with DL. The effect of DIM statistically significant in only one interaction, F x A x DL x DIM ($p = 0.0063$), and almost reaches significance in the F x G x DIM interaction ($p = 0.0624$). At DL-1 there was a difference in the range of perceived uniformity ratings, as a function of A, between the 1- and 2-D conditions at 128 c/dw. This F level corresponds to 3.66 cycles/degree of visual angle where the eye is most sensitive. The difference between DIMs may actually be a function of DL rather than a difference in the sensitivity to 2-D patterns.

Magnitude estimation results, baseline removed. An analysis of variance was conducted on the same data with the baseline (A-0) removed. Results of this analysis are listed in Table 34. This analysis revealed that the effects discussed in the preceding section were strong and that excluding the baseline condition did not radically change the results; that is, the trends were the same. Each significant result was reanalyzed using the same post-hoc tests. This section will discuss any differences between the two analyses.

For comparison, Table 35 lists the significant effects and corresponding F-test and probability values for the analyses with and without the baseline. Three effects (F x A x DL, A x DL and A x G) that are significant in the first analysis are no longer significant ($p > .05$) when the baseline is removed. One third-order effect reaches significance in the second analysis (F x A x DIM). In some cases, the effects are still significant and the trends the same; however, some differences among means occurred and these differences will be discussed.

The F x A x DL x DIM interaction is illustrated in Figure 25. Table 36 lists the results for the F-test of F x A x DL, which is significant only for the 2-D condition. The previous analysis has

TABLE 34

Analysis of Variance Summary Table for Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
<u>Between Subjects</u>				
Dimension (DIM)	1	1635.74	0.27	0.6085
Subjects within Dimension (S/DIM)	28	6138.68		
<u>Within Subjects</u>				
Frequency (F)	6	131604.13	19.16	0.0001
F-*DIM	6	977.33	0.15	0.9881
F*S/DIM	168	6373.91		
Amplitude (A)	4	157289.88	13.19	0.0001
A*DIM	4	395.01	1.56	0.1904
A*S/DIM	112	6613.07		
Display Luminance (DL)	2	24568.34	23.03	0.0001
DL*DIM	2	133.77	0.10	0.9090
DL*S/DIM	56	1037.70		
Gradient (G)	2	18723.40	10.82	0.0001
G*DIM	2	3518.10	2.10	0.1321
G*S/DIM	56	1640.00		
F*DL	12	1057.84	7.51	0.0001
F*DL*DIM	12	73.35	0.52	0.8995
F*DL*S/DIM	336	139.33		
F*A	24	5774.28	5.66	0.0001
F*A*DIM	24	272.26	2.62	0.0001
F*A*S/DIM	672	338.36		
F*G	12	1776.56	7.30	0.0001
F*G*DIM	12	394.55	1.73	0.0591

TABLE 34 (CONT)

Source of Variance	df	MS	F	p
F*G*S/DIM	336	230.24		
A*DL	8	1714.34	1.80	0.0777
A*DL*DIM	8	34.03	1.00	0.4332
A*DL*S/DIM	224	96.52		
A*G	8	827.41	0.81	0.5932
A*G*DIM	8	161.81	0.82	0.5840
A*G*S/DIM	224	111.14		
DL*G	4	464.07	5.65	0.0004
DL*G*DIM	4	51.28	0.68	0.6058
DL*G*S/DIM	112	73.71		
F*A*DL	48	70.34	0.82	0.8006
F*A*DL*DIM	48	47.68	1.60	0.0063
F*A*DL*S/DIM	1344	32.92		
F*A*G	48	116.10	1.77	0.0011
F*A*G*DIM	48	41.68	0.99	0.4994
F*A*G*S/DIM	1344	34.90		
A*DL*G	16	32.73	1.02	0.4340
A*DL*G*DIM	16	20.21	0.80	0.6872
A*DL*G*S/DIM	448	24.94		
DL*G*F	24	50.54	1.64	0.0289
D*G*F*DIM	24	29.26	1.00	0.4591
DL*G*F*S/DIM	672	28.92		
F*A*DL*G	96	24.34	1.04	0.3711
F*A*DL*G*DIM	96	26.38	1.17	0.1306
F*A*D*G*S/DIM	2688	22.93		
Total	9449			

TABLE 35

Comparison of Significant Effects for ANOVAs With and Without the A-0 Baseline

	Baseline Included		**Baseline Removed**	
Source of Variance	F	p	F	p
F	20.65	0.0001	19.16	0.0001
A	23.78	0.0001	13.19	0.0001
DL	23.68	0.0001	23.03	0.0001
G	11.42	0.0001	10.82	0.0001
F*DL	7.60	0.0001	7.51	0.0001
F*A	17.07	0.0001	5.66	0.0001
F*G	7.72	0.0001	7.30	0.0001
A*DL	17.76	0.0001	1.80	0.0777
A*G	7.44	0.0001	0.81	0.5932
DL*G	6.30	0.0001	5.65	0.0004
F*A*DL	21.40	0.0001	0.86	0.8006
F*A*DIM	0.80	0.7632	2.62	0.0001
F*G*DIM	1.71	0.0624	1.73	0.0591
F*A*G	3.33	0.0001	1.77	0.0011
F*G*DL	1.75	0.0153	1.64	0.0289
F*A*DL*DIM	1.45	0.0151	1.60	0.0063

TABLE 36

Simple-Effect F-tests for F x A x DL for One and Two Dimensions - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
F x A x DL for 1-D	48	37.35	1.13	0.2535
F x A x DL for 2-D	48	52.09	1.58	0.0076
F x A x DLx S/DIM	1344	32.92		

shown that the effects of DL strongly influence the perception of the nonuniformities and may be causing the differences in estimations for the 2-D condition.

Table 37 lists the results of F-tests on the A x DL x DIM interactions. As in the previous analysis, there is a significant interaction among A, DL, and DIM for the 128 c/dw condition. The interaction is also significant at 8 c/dw in this analysis. At 8 c/dw there is a slight drop in perceived uniformity ratings from 4 to 8 cycles for the 2-D condition. It is difficult to determine the influence of DIM because of the confound with DL. The results may be a combination of both DIM and DL.

In the previous analysis the F x A x DL interaction was significant at $p = 0.0001$. As expected, this interaction is no longer significant when the baseline is removed from the analysis.

Without the baseline the F x A x DIM interaction reached significance and is illustrated in Figure 36. Simple-effect tests by DIM listed in Table 38 indicate a significant F x A interaction for the 2-D case only. Table 39 indicates that the A x DIM interaction is significant at 4, 8, and 16 c/dw. Notice that in the 1-D case the F x A interaction closely follows the CTF. There is a larger range in perceived uniformity ratings at the middle F levels where the visual system is more sensitive. In the 2-D case, the lower F levels result in a larger range of perceived uniformity ratings. If this effect was only a function of the higher DL levels in the 2-D condition, then the results should still follow the CTF; thus, the results suggest the 2-D pattern is also contributing.

In the previous analysis the F x G x DIM interaction reached a probability level of $p =$ 0.0624. Removing the baseline only changed the probability to 0.0591. Table 40 lists the F-test results by DIM. The F x G interaction is significant for the 1-D case at $p < .05$ and for the 2-D case at $p < .01$. Recall that F x G is not significant for 1-D when the baseline is included. For both 1- and 2-D the SQ wave results in lower ratings of perceived uniformity than the SINE or TRI waves. Table 41 lists the results by F. Again, the G x DIM interaction is significant at the lower Fs: 4, 8,

TABLE 37

Simple-Effect F-tests for A x DL x DIM at Each Frequency - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
A x DL x DIM for 4 cylces/display	8	22.55	0.68	0.7095
A x DL x DIM for 8 cycles/display	8	65.75	2.00	0.0432
A x DL x DIM for 16 cycles/display	8	51.92	1.58	0.1260
A x DL x DIM for 32 cycles/display	8	16.96	0.51	0.8496
A x DL x DIM for 64 cycles/display	8	59.75	1.81	0.0711
A x DL x DIM for 128 cycles/display	8	156.42	4.75	< 0.0001
A x DL x DIM for 256 cycles/display	8	22.86	0.69	0.7007
F x A x DL x S/DIM	1344	32.92		

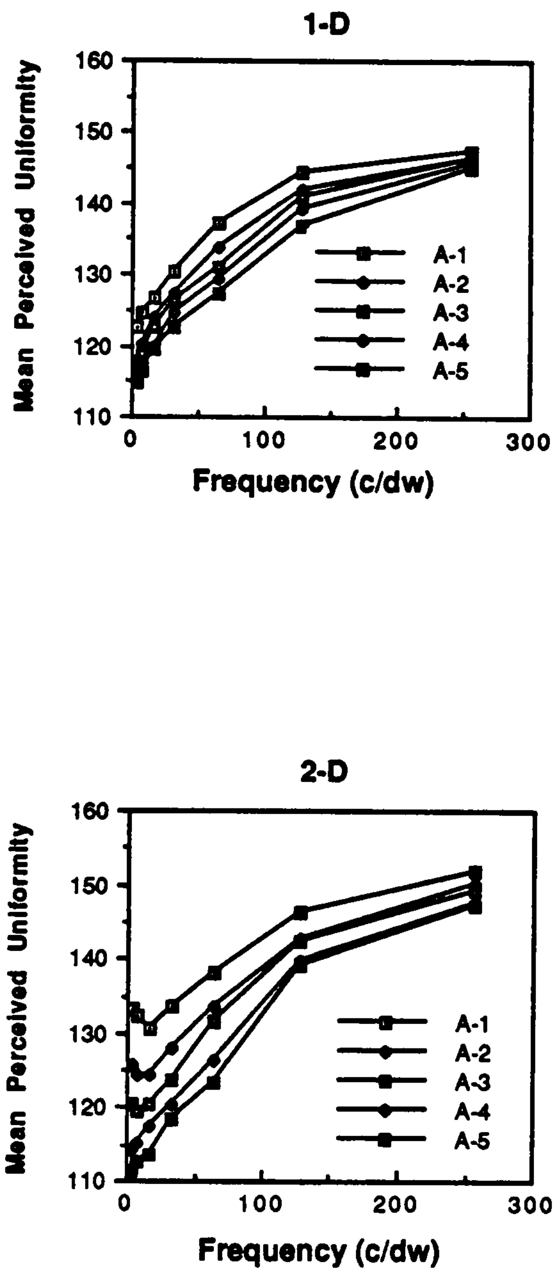


Figure 36. The F x A x DIM interaction for mean perceived uniformity, baseline removed.

TABLE 38

Simple-Effect F-tests for F x A for 1-D and 2-D - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
F x A for 1-D	24	138.12	0.41	0.9948
F x A for 2-D	24	879.65	2.60	< 0.0001
F x A x S/DIM	672	338.36		

TABLE 39

Simple-Effect F-tests for A x DIM at Each Frequency - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
A x Dim for 4 cycles/display	4	2281.73	6.74	< 0.0001
A x Dim for 8 cycles/display	4	1531.32	4.53	0.0013
A x Dim for 16 cycles/display	4	886.31	2.62	0.0340
A x Dim for 32 cycles/display	4	718.35	2.12	0.0767
A x Dim for 64 cycles/display	4	350.62	1.04	0.3856
A x Dim for 128 cycles/display	4	56.75	0.17	0.9537
A x Dim for 250 cycles/display	4	67.23	0.20	0.9383
A x F x S/DIM	672	338.36		

TABLE 40

Simple-Effect F-tests for F x G for One and Two Dimensions - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
F x G for 1-D	12	401.95	1.75	0.0554
F x G for 2-D	12	2350.41	10.21	< 0.0001
F x G x S/DIM	336	230.24		

TABLE 41

Simple-Effect F-tests for G x DIM at Each Frequency - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
G x DIM for 4 cycles/display	2	3341.02	14.51	< 0.0001
G x DIM for 8 cycles/display	2	1920.60	8.34	0.0003
G x DIM for 16 cycles/display	2	1784.00	7.75	0.0005
Gx DIM for 32 cycles/display	2	455.14	1.98	0.1397
G x DIM for 64 cycles/display	2	215.59	0.94	0.3916
G x DIM for 128 cycles/display	2	9.57	0.04	0.9608
G x DIM for 256 cycles/display	2	4.13	0.02	0.9802
G x F x S/DIM	336	230.24		

and 16 c/dw. At these F levels, the perceived uniformity ratings for the 2-D SQ wave are lower than the perceived uniformity ratings for the 1-D SQ wave. These results are consistent with results reported in the description of the F x A x DIM interaction above.

The F x A x G interaction is illustrated in Figure 27. The F-test results by F, listed in Table 42, indicate that the A x G interaction is significant at 8, 16, 32, and 64 c/dw. The perceived uniformity ratings for the SQ wave at each A level were lower than those for the SINE and TRI wave shapes. In the previous analysis, the interaction was significant also at 4 c/dw. These results support the previous research findings of De Palma and Lowry (1962) who found that lower modulations were required to detect square-wave gratings at lower spatial frequencies.

The F x A interaction is again significant and is illustrated by Figure 30. Results of a Newman-Keuls test, listed in Table 43, indicate that perceived uniformity is significantly different among A levels at all but the highest F level (256 c/dw). In the previous analysis, there was a significant difference among A levels at 256 c/dw, which indicates that the A-0 condition was contributing to the significant effect of A at 256 c/dw. Therefore, subjects could detect nonuniformities at the highest F level, although they could not determine the difference among A levels. This can be predicted by examining Table A-37 - A-42 in Appendix A which shows that the modulation for 256 c/dw is visible but the harmonics are not.

The A x G interaction is not significant without the baseline. As A increases, perceived uniformity ratings increase for all G shapes at the same rate. There are significant main effects for A and G. Tables 44 and 45 list results of Newman-Keuls tests for these main effects. Perceived uniformity is significantly lower for the SQ wave. The main effect of A indicates that the lowest A (A-1) results in perceived uniformity ratings that are significantly higher (i.e., more uniform) than those for A-2 through A-5.

TABLE 42

Simple-Effect F-test for A x G at Each Frequency - Magnitude Estimation, Baseline Removed

Source of Variance	df	MS	F	p
A x G for 4 cycles/display	8	18.96	0.54	0.8269
A x G for 8 cycles/display	8	88.88	2.55	0.0093
A x G for 16 cycles/display	8	107.19	3.07	0.0020
A x G for 32 cycles/display	8	63.88	1.83	0.0675
A x G for 64 cycles/display	8	88.23	2.52	0.0101
A x G for 128 cycles/display	8	23.97	0.69	0.7707
A x G for 256 cycles/display	8	9.23	0.26	0.9784
A x G x F x S/DIM	1344	34.90		

TABLE 43

Newman-Keuls Comparisons for A at Each Frequency- Magnitude Estimation, Baseline Removed

Amplitude	4 cycles/display MPU	8 cycles/display MPU	16 cycles/display MPU	32 cycles/display MPU
1	127.88 A	128.42 A	128.73 A	131.94 A
2	121.75 B	122.26 B	124.10 B	127.66 B
3	118.76 B	119.13 B C	121.37 B C	125.05 B C
4	114.95 C	116.29 C D	118.63 C D	122.51 C D
5	113.90 C	114.56 D	116.63 D	120.61 D

Amplitude	64 cycles/display MPU	128 cycles/display MPU	256 cycles/display MPU
1	137.60 A	144.33 A	149.59 A
2	133.62 B	142.43 A B	148.31 A
3	131.37 B	141.71 B	147.80 A
4	127.85 C	139.56 B C	146.60 A
5	125.40 C	137.94 C	146.06 A

MPU - mean perceived uniformity
Note: Means with the same letter are not significantly different, $p > 0.05$

TABLE 44

Newman-Keuls Comparisons for Amplitude - Magnitude Estimation, Baseline Removed

Amplitude	MPU				
1	135.64	A			
2	131.45		B		
3	129.31		B	C	
4	126.63			C	D
5	124.90				D

MPU - mean perceived uniformity
Note: Means accompanied by the same letters are not significantly different, $p > .05$

TABLE 45

Newman-Keuls Comparisons for Gradient - Magnitude Estimation, Baseline Removed

Gradient	MPU		
TRI	133.31	A	
SINE	131.02	A	
SQ	126.43		B

MPU - mean perceived uniformity
Note: Means accompanied by different letters are not significantly different, $p > .05$

The A x DL interaction is also no longer significant when the baseline is removed. Perceived uniformity ratings increase as A increases at the same rate for all DL levels.

An analysis of the third-order effect of F x G x DL and the second-order effects of F x G, and G x DL, indicates that trends are the same when the baseline is removed; therefore, results will not be repeated here.

Summary. When the baseline condition is removed and the data are reanalyzed, the overall results are essentially the same. The trends remain unchanged. Listed below are summaries of the major changes in the results which occur when the baseline is removed.

(1) The F x A x DL interaction is not significant when the baseline is removed. When DL increases perceived uniformity ratings increase with increasing F at the same rate for each A level.

(2) The F x A x DIM interaction reaches significance. The F x A interaction is only significant for the 2-D condition although trends are similar for the 1-D condition.

(3) The A x G and the A x DL interactions are no longer significant when the baseline is removed. As A increases, perceived uniformity ratings decrease at the same rate for all G shapes, and at the same rate for all DL levels.

(4) Removal of the baseline shows that subjects can detect the difference between an all-pixel-on uniform screen (baseline) and the highest F level, 256 c/dw (2 pixels on 2, pixels off).

Magnitude Estimation Conclusions

Many of the effects of the magnitude estimation task are both statistically significant and meaningful. Although subjects' random search performance is not detrimentally influenced by nonuniformities, subjects are sensitive to the nonuniformities. Defining nonuniformities in terms of F, A, DL, G, and DIM was successful, and the effects on the perception of uniformity as caused by each variable are discussed briefly below.

Display luminance. DL is an influential variable and interacts with many of the other variables. In general, as DL increases, perceived uniformity decreases (when nonuniformities are present). When nonuniformities are not present (baseline condition), subjects rate DL-3 as being more uniform in luminance than the lower DL levels, which may be a function of the instructions which stated that they were to rate how uniform in "luminance" the screen appeared. Subjects may have been looking for luminance although they were instructed not to rate the screen based on how "bright" it appeared.

DL also interacts with F. The effects of DL are stronger at middle F levels and these results resemble the CTF of the visual system. Also, the effect of DL is greater for SQ than for SINE or TRI nonuniformities. This effect is also consistent with previous research in spatial vision which shows that lower modulations are required to detect SQ waves.

Amplitude. As A increases, perceived uniformity decreases and the effect of A interacts with F. As F increases, the effect that A has on perceived uniformity decreases. Again, these results can be explained by models of spatial vision. The tables in Appendix A are predictive of these results. These tables illustrate that as F increases the modulations of the fundamental frequency and harmonics do not reach visual threshold detection levels. At 4, 8, and 16 c/dw the fundamental and 3rd, 5th, and 7th harmonics (for the SQ and TRI wave) have modulations above detection thresholds. At 32 c/dw, the 7th harmonic is no longer detectable for many of the A levels. At 64 c/dw the 5th harmonic is beginning to be undetectable. At 128 cd/w, detection of the 3rd harmonic is limited. At 256 c/dw, the modulation passed by the display for the fundamental frequency is 88% of the modulation passed at 4 c/dw and all harmonics are undetectable. These results verify previous vision research investigating the CTF of the visual system to SQ wave forms.

Gradient. Subjects consistently rated the TRI and SINE waves the same even though the TRI wave had harmonics that were visible at the lower F levels. The SQ wave resulted in significantly lower ratings of perceived uniformity than SINE and TRI waves. Also, the harmonics of the SQ wave are more visible (i.e., higher modulations) than the harmonics of the TRI wave as illustrated in tables located in Appendix A. For certain combinations of F, A, and DL, harmonics of the TRI are not visible while harmonics of the SQ wave are. As F increased, the harmonics of the SQ wave did not reach threshold detection levels as discussed above. At 128 and 256 c/dw subjects could not tell the difference among G shapes at their viewing distance (45.7 cm). The tables in Appendix A are predictive of these results. The effect of the SQ shape decreased as the harmonics became undetectable. These results also verify previous vision research investigating the CTF of the visual system for SQ wave forms.

Dimension. The effect of DIM is difficult to interpret. It is obvious that DL is an influential variable. Therefore, it is not unlikely that DL played a prominent role in the effect of DIM due to the confounding of the variables. Additional research is necessary to determine the difference between 1- and 2-D nonuniformities. If DIM was strongly influencing perceptions, then DIM probably would have interacted with more variables.

Performance Modelling

Developing a model which can successfully relate physical measures of nonuniformities to human performance data will allow human factors engineers and display designers to determine if nonuniformities present in the display system will interfere with performance without having to conduct numerous performance studies. A performance modelling approach was used in an attempt to predict human performance in the presence of nonuniformities. Results of the analysis discussed in the preceding section indicated that ST and CR performance are not significantly influenced by the presence of nonuniformities; therefore, modelling the prediction of ST and CR would not be meaningful. Instead, models for predicting perceived uniformity of the nonuniformities were constructed and evaluated.

Modelling approach. Multiple linear regression techniques are used for human performance modelling. The approach taken in this analysis is to compare alternative models based on multiple criteria for selection of the best models. Models were examined for multicollinearity using the diagnostic techniques of variance inflation factors (VIF) and variance proportions for each regressor. Also, an examination of residuals was performed. For each model the coefficient of determination (R^2), Mallows Cp-statistic (an estimate of bias), and the mean square error (MSE) were examined. Models were developed with the data set that did not include the baseline because the baseline data would influence the regression and prediction of subjective impressions of a uniform screen was not the objective.

The SAS procedures MAXR and STEPWISE were used to determine subsets of models for further evaluation. The stepwise techniques choose variables to enter into the model based on an increase or decrease in the value of R^2 and perform significance tests for each entering variable. However, R^2 will increase as the number of regressor variables entering the model increases, introducing the possibility of overfitting the model. The selection procedures in stepwise regression can also result in underestimation of the true model error. Therefore, the significance levels for the tests on entering variables may not be valid. A high criterion (0.50) for the entering variables in forward selection was used to combat this problem. The MAXR procedure also uses R^2 for variable screening but significance tests on the variables are not performed on the entering variables, so this procedure considers all possible models. That is, this procedure selects one model for each number of regressor variables.

Regressor variables. The regressor variables selected for model building are listed in Table 46. Variables were selected that would describe the nonuniformities in physical terms. The

TABLE 46

Regressor Variable Definitions

FUNDF	Fundamental Frequency.
$FUNDF^2$	Square of the Fundamental Frequency.
F(SF)	Function of Spatial Frequency, the CTF value at each fundamental frequency.
$[F(SF)]^2$	Square of Function of Spatial Frequency.
F3	Frequency of the 3rd harmonic for SQ and TRI wave shapes.
F5	Frequency of the 5th harmonic for SQ and TRI wave shapes.
F7	Frequency of the 7th harmonic for SQ and TRI wave shapes.
MODSINE	Displayed luminance modulation for the SINE at the fundamental frequency.
MODSQ	Displayed luminance modulation for the SQ at the fundamental frequency.
MODTRI	Displayed luminance modulation for the TRI at the fundamental frequency.
MOD3SQ	Displayed luminance modulation for the SQ at the 3rd harmonic frequency.
MOD5SQ	Displayed luminance modulation for the SQ at the 5th harmonic frequency.
MOD7SQ	Displayed luminance modulation for the SQ at the 7th harmonic frequency.
MOD3TRI	Displayed luminance modulation for the TRI at the 3rd harmonic frequency.
MOD5TRI	Displayed luminance modulation for the TRI at the 5th harmonic frequency.
MOD7TRI	Displayed luminance modulation for the TRI at the 7th harmonic frequency.
G1	Categorical variable to describe the variable G. TRI wave was coded as 1, SINE and SQ as 0.
G2	Categorical variable to describe the variable G. SQ wave was coded as 1, SINE and TRI as 0.
DIM	Categorical variable to describe the variable DIM. 1-D patterns are coded as 0, 2-D patterns are coded as 1.

spatial frequencies of the nonuniformities were described by the fundamental frequency (FUNDF) in cycles/degree of visual angle. The 3rd, 5th, and 7th harmonic frequencies (3F, 5F, 7F) of the SQ and TRI wave were also included. A function of spatial frequency F(SF) was also defined, and is the CTF value at each fundamental frequency or CTF(w). The CTF values were taken from the CTF curve determined by van Meeteren et al. (1966) and is illustrated in Figure 3.

The results presented in the previous ANOVA section indicate that there is a curvilinear trend in the data for the variable FUNDF. This is a function of the visual system's response to spatial frequency. Quadratic terms $FUNDF^2$ and $F(SF)^2$ were also included in an attempt to account for this curvature.

The A and DL levels were described by modulation. The modulations at each fundamental and harmonic frequency were included, where modulation is defined by Equation 1. These modulation values can be found in tables in Appendix A. MODSIN, MODSQ, and MODTRI refer to the modulations for the fundamental frequencies for the SINE, SQ, and TRI waves, respectively. MOD3SQ, MOD5SQ, and MOD7SQ refer to the modulations at each harmonic for the SQ shape, and modulations for TRI are defined similarly.

Note that the SINE waveform does not have harmonics; therefore, the variables F3, F5, and F7 for the SINE conditions were coded as zero in order to complete the matrix. In reality they are nonexistent. A similar coding scheme is used for the modulation variables. MODSINE is coded as zero for SQ and TRI conditions, MODSQ is coded as zero for SINE and TRI conditions and so forth. The same is true for the modulation variables describing the harmonics. In order to use the models specified in this study the same coding scheme must be applied. Other coding schemes were tested but resulted in problems of multicollinearity which caused instability in the coefficients, and results were uninterpretable.

The variables G and DIM were included as categorical variables. G had three levels (SINE, TRI, and SQ) and required two variables to describe the categories. These variables were termed G1 and G2. Inclusion of G1 would indicate that TRI influences the regression. Inclusion of G2 would indicate that SQ influences the regression. If neither G1 nor G2 are included, SINE is influencing regression. DIM had two levels and required only one variable to describe the categories. Inclusion of the variable DIM would indicate that the 2-D case was important in the model.

Analysis and results. A regression analysis was first performed using the variables described above. The best-fit models are listed in Table 47. Overall, modelling was not very successful. A large proportion of the variance is unaccounted for by the models. Large MSE and small C_p values indicate poor prediction and fit. The most optimal fit of the estimation data is the 9-variable model. As expected, modulation variables have negative signs indicating that as modulation increases, perceived uniformity decreases. Modulations of the 7th harmonic for the SQ wave and the 5th harmonic for the TRI wave are also included in the model. Inclusion of these variables support the theory that if modulations of the higher harmonics are above the subject's visual thresholds, they will influence subjective impressions of the nonuniformities. Inclusion of 7F and MOD7SQ indicates that the 7th harmonic for the square wave is influencing estimations. However, use of these models for prediction is not feasible since most of the variance (over 70 percent) is unaccounted for by the models.

An inspection of the ANOVA results in Table 34 showed that a large proportion of variance is contributed by differences among subjects, which is unexplained by the models described above. To determine if the between-subjects variance could account for part of the unexplained variance, subject (SUB) was included in the analysis as a categorical variable. The best fitting model is shown in Table 48 and is an underfit as indicated by the large C_p statistic. In

TABLE 47

Best-fit Regression Models for Perceived Uniformity

Nine-Variable Model

Variables	Parameter Estimation	Beta Weights
Intercept	125.6150	0
7F	1.0648	0.8841
DIM	4.6042	0.1126
MODSIN	-16.1796	-0.1806
MODSQ	-8.8411	-0.1256
MODTRI	-13.4234	-0.1214
MOD7SQ	-126.6289	-0.1942
MOD5TRI	-37.9093	-0.0544
F(SF)	-0.5551	-0.4944

$R^2 = 0.2941$ MSE = 295.5118 $C_p = 8.562$ N = 9450

Ten-Variable Model

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.2926	0
7F	1.0640	0.8835
DIM	4.6040	0.1126
G2	-2.0100	-0.0463
MODSIN	-17.4936	0.1952
MODSQ	-6.7003	-0.0952
MODTRI	-15.0657	-0.1363
MOD7SQ	-127.4869	-0.1955
MOD5TRI	-37.7642	-0.0542
$FUNDF^2$	-0.5547	-0.4940

$R^2 = 0.2944$ MSE = 295.3901 $C_p = 5.67$ N = 9450

TABLE 48

Best-fit Regression Model for Perceived Uniformity with Subject as a Categorical Variable.

Twelve-Variable Model

Variables	Parameter Estimation	Beta Weights
INTERCEPT	125.5421	0
FUNDF	7.7486	0.9191
GRAD2	-1.9898	-0.0459
DIM	3.6826	0.0900
MODSIN	-17.1603	-0.1915
MOD5SQ	-130.5509	-0.2811
MOD3TRI	-77.4318	-0.1852
$FUNDF^2$	-0.6209	-0.5530
SUB2	19.1872	0.1684
SUB21	8.8967	0.0781
SUB26	2.4951	0.0219
SUB30	2.4274	0.0213

$R^2 = 0.3267$ MSE = 281.9434 $C_p = 12.71$ N = 9450

this model four subjects were included. An examination of raw data indicates that these subjects had large ranges in their estimations, particularly SUB2 and SUB21. When all SUB variables were included in the regression, R^2 increased to 0.3292 from 0.3267 and the additional SUB parameters did not contribute significantly to the model.

A large proportion of the variance is still unexplained by the model described above. When SUB is entered as a categorical variable only the between-subject variance is accounted for. The ANOVA results listed in Table 34 indicated that SUB is interacting with the other variables (i.e, large MSE values for error terms). Also, when SUB is included as a categorical variable the model is specific to the individual subjects in the experiment and is not easily generalizable. The objective of model building is to develop a model to predict overall impressions of nonuniformities. Therefore, the next step was to predict the mean perceived uniformity across all subjects for each condition.

Best-fit models using mean perceived uniformity are shown in Table 49. This modelling approach was more successful than previous attempts. A greater proportion of the variance is accounted for by the models as indicated by the higher values of R^2 and lower MSE. Modulation variables have negative coefficients as expected. FUNDF and the quadratic term $FUNDF^2$ are also included in all models. In general, the models are either overfit or underfit as indicated by the C_p values. The first 10-variable model listed in Table 49 is perhaps the optimum model although it is an underfit (C_p is too large) and is therefore biased. Substituting MOD7SQ for MOD5SQ and MOD5TRI for MOD3TRI in the second 10-variable model increased R^2 by only .002 but the model becomes an overfit as indicated by the low C_p statistic. The 11-variable model is an overfit, and the increase in R^2 and decrease in MSE are minimal as coefficients are added to the regression.

Although the first 10-variable model does not account for 16% of the variance, the coefficients in this model are meaningful. As expected, frequency variables (FUNDF and

TABLE 49

Best-fit Regression Model for Perceived Uniformity Collapsed Across Subjects

Eight-Variable Model

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.2970	0
FUNDF	-7.7486	1.5557
GRAD2	-1.9898	-0.0776
DIM	4.3731	0.1810
MODSIN	-17.1603	-0.3241
MOD5SQ	-130.5509	-0.4758
MOD3TRI	-77.4318	-0.3135
$FUNDF^2$	-0.6209	-0.9360

$R^2 = 0.8403$ MSE = 23.6182 $C_p = 14.19$ N = 630

Nine-Variable Model

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.3175	0
FUNDF	7.7970	1.5654
GRAD2	-2.4521	-0.0957
DIM	4.4556	0.1844
MODSIN	-17.6107	-0.3326
MODTRI	-9.1898	-0.1407
MOD5SQ	-127.4514	-0.4645
MOD3TRI	-44.8689	-0.1817
$FUNDF^2$	-0.6143	-0.9269

$R^2 = 0.8411$ MSE = 23.5334 $C_p = 12.93$ N = 630

TABLE 49 (CONT)

Ten-Variable Model (1)

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.1049	0
FUNDF	7.8882	1.5837
GRAD2	-1.8331	-0.0715
DIM	4.6001	0.1904
MODSIN	-17.6953	-0.3342
MODSQ	-3.5033	-0.0843
MODTRI	-11.4847	-0.1758
MOD5SQ	-110.9931	-0.4045
MOD3TRI	-36.3324	-0.1471
$FUNDF^2$	-0.6157	-0.9282

$R^2 = 0.8416$ MSE = 23.4920 $C_p = 12.83$ N = 630

Ten-Variable Model (2)

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.2919	0
FUNDF	7.4501	1.4958
GRAD2	-2.0096	-0.0784
DIM	4.6040	0.1905
MODSIN	-17.4937	-0.3304
MODSQ	-6.6998	-0.2307
MODTRI	-15.0647	-0.1611
MOD7SQ	-127.4926	-0.3309
MOD5TRI	-37.7712	-0.0978
$FUNDF^2$	-0.5549	-0.8365

$R^2 = 0.8436$ MSE = 23.1943 $C_p = 4.93$ N = 630

TABLE 49 (CONT)

Eleven-Variable Model

Variables	Parameter Estimation	Beta Weights
INTERCEPT	126.37.58	0
FUNDF	7.1883	1.4432
GRAD2	-2.1777	-0.0850
DIM	4.6088	0.1907
MODSIN	-17.4089	-0.3288
MODSQ	-9.8321	-0.2365
MODTRI	-16.6612	-0.2551
MOD5SQ	83.8890	-0.3657
MOD7SQ	-216.1321	-0.5609
MOD7TRI	-39.5841	-0.0677
$FUNDF^2$	-0.5139	-0.7746

$R^2 = 0.8441$ MSE = 23.1683 $C_p = 5.25$ N = 630

FUNDF^2) are included in the model and, as indicated by the beta weights, contribute substantially to explanation of the variance. Note that the signs on the beta weights indicate the direction of the effect, not the magnitude of the weight; that is, relative magnitude of the beta weights are obtained by comparing absolute values. The MOD variables of the fundamental frequencies for each wave shape are also included in the model. The MOD variables describe the A and DL levels of each nonuniformity condition. As modulation increases perceived uniformity decreases; that is, the display appears more nonuniform to subjects. The coefficients for MOD5SQ and MOD3TRI are also important in the model and support the theory that if modulations of the harmonics are above visual threshold, they will impact impressions of the nonuniformities. Inclusion of these variables also add support to the theory that the visual system behaves as a Fourier analyzer in the spatial domain. Note that correlations among MOD variables for harmonics indicate that different harmonic values could be used instead.

The effect due to the categories G2 and DIM are significant in partial-F tests at $p < 0.0001$. Inclusion of G2 in the model indicates that perceived uniformity is influenced by the SQ wave shape and also that wave shape is an important variable in defining nonuniformity as originally expected. The inclusion of the coefficient DIM indicates that 2-D nonuniformities influence estimations of perceived uniformity, although it is not possible to determine if the effect is due to the pattern or the higher DL levels. It should be noted that categorical variables influence the intercept of the regression line by a constant amount but do not affect the rate of change or slope of the regression line. If a SQ wave shape is not to be predicted, then the coefficient can be set to 0.

The nonuniformities for the 1- and 2-D conditions are completely described by the MOD terms, which take into account DL levels; therefore, the variable DIM should not be important to the model. Inclusion of this variable may indicate that the 2-D pattern is influencing perceived uniformity beyond the three modulation measures.

GENERAL DISCUSSION AND CONCLUSIONS

Human Performance and Current Standards

The results of this research indicate that very noticeable spatial luminance nonuniformities do not appreciably affect performance for search type tasks. The American National Standard for Human Factors of Visual Display Terminal Workstations (1988) recommends that the luminance variation from the center to the edge of the active display area should vary no more than 50% of that of the center luminance. In reference to high frequency spatial luminance nonuniformities, the standard recommends that unintended luminance variations shall not vary by more than 50% within an area the size of half a degree of arc, at any position on the screen. (This value is calculated based on the display design viewing distance.) The nonuniformities in this study exceeded these recommendations and search performance was relatively unaffected. The ANSI standard is written in reference to displays that are to be used for alphanumeric or word processing and reading type tasks. This research indicates recommendations are also appropriate for search tasks with non-alphanumeric symbols. Results of this type will most likely apply to reading type tasks because it has been found that subjects are able to perform reading tasks or contextual tasks under adverse conditions (Albert, 1975; Lloyd et al., 1988).

The type of task performed is an important consideration. There is limited research investigating the sensitivity of different task types for research involving presentation of information on visual displays (Decker et al., 1987). Research which correlates performance among different tasks to predict results across task types is also lacking. Photointerpretation tasks or information extraction from literal images, such as medical imagery, will most likely show different results.

Although subjects were able to perform the random search task in the presence of nonuniformities, results from the magnitude estimation task indicate that subjects were sensitive to nonuniformities in terms of their impressions of perceived uniformity. Sensitivity to the nonuniformities was noted during the random search task. While performing the search task, many subjects complained about the images and found them annoying. Some subjects commented that the SINE waveforms appeared blurry and that performing the task was fatiguing. Focusing on the SINE wave is difficult because there are no edges.

Most displays currently on the market do not exhibit the levels of nonuniformity used in this study. However, nonuniformities may be caused by components or processes of a display system other than the display hardware. Possible causes of nonuniformities which may result in high levels of nonuniformities include signal processing techniques necessary for transformation of signals so they can be displayed or enhanced, or coding techniques such as spatial dithering or half-toning.

Relation to Previous Research

Display failures. As pointed out in the literature review there is limited research investigating the effects of nonuniformities. Abramson and Snyder (1984), Decker et al. (1988), and Lloyd et al. (1988) investigated the effects of display failures which can be considered as high frequency nonuniformities. Cell and line failures were introduced onto the display and results indicated that these types of nonuniformities were degrading to both search and reading performance. The high frequency nonuniformities in the current study were not detrimental to search performance. A possible explanation for the difference in results is that in the previous research the failures introduced onto the display were random, while the nonuniformities in this study were not. In fact, the nonuniformities had the appearance of a background to the task information rather than an interruption in the image and apparently subjects were able to ignore the nonuniformities. The failures on the other hand, degraded the information by removing parts of the images or adding extra cells or lines resulting in the appearance of visual noise.

The nonuniformities used in this study were additive. When the display luminance was increased the symbol luminance increased. Therefore, the modulations of the symbols and maps remained above recommended levels of modulation (e.g., ANSI, 1988). Introduction of failures degrade the image and change the modulation of symbols or characters as well. Introduction of nonuniformities that are not additive will probably result in further degradation of the image and performance will deteriorate.

Effects of visual noise. A significant amount of research has been conducted in the past investigating the effects of visual noise on detection of targets, including detection of sine-wave patterns. Noise is defined as an unwanted signal or disturbance in a system which can obscure information of interest (Cohen and Lashly, 1986). Results of research on this topic indicate that performance is affected by the type of noise (e.g., random), the bandwidth of the noise, amplitude, and frequency (Carter and Henning, 1970; Pollehn and Roehrig, 1970; Snyder, Keesee, Beamon, and Aschenbach, 1974; Stromeyer and Julesz, 1972), and that noise has detrimental effects on performance. The differences in findings among studies investigating noise and this research can be explained by several factors. As mentioned previously, the modulations of the symbols in this study were not degraded by the nonuniformities, whereas research investigating noise effects has shown degradation in the symbol modulations (Snyder et al., 1974). In addition, the noise presented in past research contains a band of spatial frequencies (i.e., broad band noise or narrowband noise) and the noise is often random noise where there is equal power at all spatial frequencies. Noise masks targets whose spatial frequencies are around the center frequency of the noise. In this study nonuniformities were centered at only one spatial frequency (for the given condition) with power at that spatial frequency. The targets were always at a spatial frequency higher than the nonuniformities. Targets and maps were created using one pixel width lines, and the highest frequency nonuniformity was 2 pixels on and 2 pixels off.

Also, broadband random noise is unstructured. Mitchell (1976) found that higher thresholds are necessary for detection of unstructured patterns than structured patterns. If subjects can determine the structure of a pattern they may find it easier to ignore.

Definitions and Measurement

One of the objectives of this research was to determine a method for describing nonuniformities such that they can be measured. Each of the variables chosen to characterize the nonuniformities was found to be important. These variables were chosen so that Fourier analysis techniques could be used to describe the nonuniformities in terms of their sine wave components. A regression model was developed to predict subjective impressions of perceived uniformity based on the sine wave content of the image. These results indicate that developing models based on Fourier analysis is a viable technique for describing and measuring display spatial nonuniformities.

Several researchers have utilized Fourier analysis to derive optimal dither or halftone patterns to minimize unwanted textures (Allenbach and Liu, 1976; Bayer, 1973; Kemisch and Roetling, 1973). Spatial dithering is a coding technique which uses fixed size dots (or pixels) coded as on or off and arranged spatially in a fixed array. An image with multiple intensity levels can be encoded into fewer intensity levels or a binary image (2 levels or 1 bit). Half-toning is a technique used in printing and photography where the dot size and shape are manipulated to obtain a binary output image (Bryngdahl, 1978). These approaches are relevant to the topic of nonuniformity because these techniques are presenting nonuniformities into the image and relying on the visual system to integrate out the nonuniformity. Researchers have been interested in determining the best dither patterns and halftone patterns to minimize textures, contouring, Moire patterns, and the perception of the dither patterns.

Allenbach and Liu (1976) used a random quasiperiod halftone process to try to eliminate Moire effects that can be introduced when halftone screens are used. They used Fourier techniques to describe the output image and compared a periodic image with a quasiperiodic image. Although authors did not use observers to rate the different patterns in any subjective or objective manner, they did illustrate that Fourier analysis can be used to describe the images. The nonuniformities used in the current study were periodic; however, nonuniformities may also be random, or quasiperiodic due to the signal processing or coding technique used.

Although researchers have been using Fourier analysis techniques to describe dither and halftone patterns, they have not validated the method using objective or subjective performance evaluations. Therefore, it was not possible to determine nonuniformity recommendations based on research in the area of dither or half-toning. This research bridges a gap between research which only mathematically describes dither patterns and performance. This research shows that knowledge of the Fourier coefficients of nonuniformity patterns and the CTF of the visual system can be used to predict subjective impressions. Further research is still needed to determine if objective performance can also be predicted and whether objective performance can be predicted from subjective impressions. Also, empirical data relating Fourier coefficients and impressions of dither and halftone patterns are still needed.

Spatial Vision

The results of this investigation are in strong concurrence with previous research in the area of spatial vision which theorizes that the visual system behaves as a Fourier analyzer in the spatial domain. De Palma and Lowry (1962) found that threshold detection is lower for a square wave than sine waves. As previously discussed, the fundamental frequency of the square wave is $4/\pi$ or 1.273 higher than that of the sine wave, and the harmonics of the square wave contribute to detection. The application of Fourier analysis is formed on the basis of research on spatial frequency models. A competing theory in vision research is that the visual system contains edge detectors which could be contributing to the difference in detection between the sine and square waves. The purpose of this study was not to compare spatial frequency filter models with edge detection models for describing how the visual system processes spatial information. A complete understanding of the underlying visual processes is not complete. However, Fourier techniques and the spatial frequency approach can be applied to describe the nonuniformities and predict performance and have also been successfully applied to other research in the area of visual displays (Snyder, 1980). Whether the CTF can be described by spatial frequency models or edge detectors or both, researchers do agree on the curves of the CTF.

The results of the subjective impressions of perceived uniformity follow the CTF of the visual system. In many cases, previous researchers have only reported results using one or two well-trained subjects. This research, with a much larger subject population, validates previous research in terms of the CTF. This indicates that smaller subject pools can be successfully used in research of this kind.

Future Research Needs

Research investigating the effects of nonuniformities is still needed. The role of 1- versus 2-dimensional nonuniformities was not adequately assessed. Also, the nonuniformities in this study were added to the symbol luminances; therefore, modulations were always well above recommended levels. Nonuniformities will not always be additive and effects of nonuniformities which change the information presented should be investigated. If the same techniques used in this study are also used to define and measure nonuniformities in future studies then prediction across studies would be possible.

It would be interesting to predict subjects' impressions of dither or halftone patterns which have been described in terms of their Fourier components in the literature. After predicting impressions and perhaps objective performance, the prediction could then be validated by performing empirical research using the images. Unfortunately, such measurement requires a capability beyond the currently available commercial state of the art.

The measurement and analytical technique used in this study to describe the nonuniformities should be validated through photometric measurements of the nonuniformities. Photometric measurements of each condition were not possible in this study because the measurement system was not sensitive enough to measure the levels used in this study .

In addition to the Fourier analysis technique used in this study, other quantitative approaches should be investigated. A technique which quantifies the difference between the original image and the same image after nonuniformities have been introduced may be a useful measure for predicting performance. In addition, an alternative coding scheme for describing the variables to be used in multiple regression models should be investigated. To use the prediction model in this study the same coding scheme is necessary.

It is recommended that research be conducted which investigates the effects of nonuniformities on performance with other tasks. If performance from objective tasks can be correlated with subjective task performance, information from subjective performance can be used in the design processes. Objective performance data are often more costly to obtain than subjective data. Predicting across different types of tasks would also be beneficial to design of visual display systems.

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APPENDIX A

DISPLAYED LUMINANCE MODULATIONS FOR EACH CONDITION

Table A-1
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-1.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.1642	0.2090	0.1331	0.0650	0.0424	0.0400	0.0259	0.0289	0.0186
0.0033	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2										
a_0	Displayed Luminance Modulation	0.2647	0.3370	0.2146	0.1008	0.0666	0.0630	0.0410	0.0458	0.0296
0.0034	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3										
a_0	Displayed Luminance Modulation	0.3521	0.4483	0.2854	0.1297	0.0867	0.0821	0.0539	0.0600	0.0391
0.0035	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-1Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-1.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4	Displayed Luminance									
a_0	Modulation	0.4937	0.6286	0.4002	0.1729	0.1174	0.1114	0.0739	0.0821	0.0539
0.0039	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u>										
5	Displayed Luminance									
a_0	Modulation	0.5714	0.7276	0.4632	0.1948	0.1335	0.1267	0.0846	0.0939	0.0619
0.0042	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

TableA-2
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-2.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5f_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u> 1 a_0	Displayed Luminance Modulation	0.1456	0.1854	0.1180	0.0581	0.0378	0.0357	0.0230	0.0257	0.0165
0.0154	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u> 2 a_0	Displayed Luminance Modulation	0.2357	0.3001	0.1910	0.0907	0.0597	0.0565	0.0367	0.0410	0.0265
0.0157	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u> 3 a_0	Displayed Luminance Modulation	0.3230	0.4112	0.2618	0.1203	0.0801	0.0758	0.0496	0.0553	0.0359
0.0161	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-2 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-2.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.4479	0.5703	0.3630	0.1594	0.1077	0.1021	0.0675	0.0751	0.0492
0.0177	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.5189	0.6607	0.4206	0.1801	0.1227	0.1164	0.0774	0.0860	0.0565
0.0185	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-3
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-3.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0977	Displayed Luminance Modulation	0.1192	0.1517	0.0966	0.0480	0.0311	0.0294	0.0189	0.0212	0.0136
	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0 0.0988	Displayed Luminance Modulation	0.1978	0.2518	0.1603	0.0773	0.0506	0.0478	0.0310	0.0346	0.0223
	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0 0.1005	Displayed Luminance Modulation	0.2736	0.3484	0.2218	0.1038	0.0687	0.0650	0.0424	0.0473	0.0306
	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-3 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 4 cycles/display at DL-3.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4	Displayed Luminance Modulation									
a_0		0.3784	0.4817	0.3067	0.1381	0.0925	0.0877	0.0576	0.0642	0.0418
0.1081	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u>										
5	Displayed Luminance Modulation									
a_0		0.4438	0.5651	0.3598	0.1582	0.1068	0.1013	0.0670	0.0745	0.0487
0.1113	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-4
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-1.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.3230	0.4112	0.2618	0.1203	0.0801	0.0758	0.0496	0.0553	0.0359
0.0161	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.4410	0.5615	0.3575	0.1573	0.1062	0.1007	0.0666	0.0740	0.0484
0.0195	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.6439	0.8198	0.5219	0.2142	0.1479	0.1405	0.0943	0.1045	0.0692
0.0205	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-4 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-1.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.7440	0.9473	0.6031	0.2395	0.1670	0.1589	0.1074	0.1189	0.0791
0.0230	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.8316	1.0000	0.6741	0.2604	0.1831	0.1744	0.1185	0.1310	0.0876
0.0285	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0= Luminance at DL-1(cd/m^2) or DC Value

Table A-5
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-2.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance Modulation	0.2884	0.3672	0.2338	0.1088	0.0721	0.0682	0.0445	0.0497	0.0322
a_0 0.0615	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2	Displayed Luminance Modulation	0.3982	0.5070	0.3228	0.1443	0.0969	0.0918	0.0605	0.0673	0.0439
a_0 0.0668	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3	Displayed Luminance Modulation	0.5913	0.7528	0.4793	0.2002	0.1375	0.1305	0.0872	0.0968	0.0639
a_0 0.0687	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-5 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-2.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.6864	0.8739	0.5564	0.2252	0.1561	0.1484	0.0999	0.1107	0.0734
0.0819	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.7810	0.9944	0.6330	0.2485	0.1739	0.1655	0.1121	0.1240	0.0827
0.0972	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-6
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-3.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0	Displayed Luminance Modulation	0.2350	0.2992	0.1905	0.0905	0.0596	0.0563	0.0366	0.0409	0.0264
0.3027	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0	Displayed Luminance Modulation	0.3280	0.4177	0.2659	0.1219	0.0812	0.0769	0.0504	0.0561	0.0365
0.3208	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0	Displayed Luminance Modulation	0.5016	0.6386	0.4065	0.1751	0.1191	0.1130	0.0750	0.0833	0.0547
0.3224	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-6 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 4 cycles/display at DL-3.

Frequency		F_1 (0.1150)			$3F_1$ (0.3450)		$5F_1$ (0.5750)		$7F_1$ (0.8050)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation									
a_0		0.5975	0.7607	0.4843	0.2019	0.1387	0.1317	0.0881	0.0977	0.0645
0.3428	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Modulation									
a_0		0.6942	0.8839	0.5627	0.2271	0.1576	0.1499	0.1009	0.1118	0.0742
0.3875	CTF value	0.0135	0.0135	0.0135	0.0077	0.0077	0.0070	0.0070	0.0069	0.0069
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-7
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 8 cycles/display at DL-1.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1 a_0	Displayed Luminance Modulation	0.1638	0.2085	0.1328	0.0650	0.0424	0.0399	0.0258	0.0288	0.0185
0.0033	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	00.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2 a_0	Displayed Luminance Modulation	0.2641	0.3362	0.2141	0.1007	0.0666	0.0629	0.0410	0.0456	0.0295
0.0034	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3 a_0	Displayed Luminance Modulation	0.3513	0.4473	0.2847	0.1297	0.0867	0.819	0.0537	0.0598	0.0389
0.0035	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-7 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 8 cycles/display at DL-1.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4 a_0	Displayed Luminance Modulation	0.4925	0.6271	0.3992	0.1728	0.1174	0.1112	0.0738	0.0818	0.0537
0.0039	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5 a_0	Displayed Luminance Modulation	0.5701	0.7258	0.4621	0.1947	0.1334	0.1265	0.0844	0.0935	0.0616
0.0042	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-8
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 8 cycles/display at DL-2.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.1453	0.1850	0.1178	0.0581	0.0378	0.0356	0.0230	0.0256	0.0165
0.0154	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2										
a_0	Displayed Luminance Modulation	0.2351	0.2994	0.1906	0.0907	0.0597	0.0564	0.0366	0.0408	0.0264
0.0157	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3										
a_0	Displayed Luminance Modulation	0.3222	0.4103	0.2612	0.1203	0.0801	0.0757	0.0495	0.0551	0.0358
0.0161	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-8 Continued
Displayed Luminance modulations for the fundamental frequency (F_1) and harmonics for 1-D, 8 cycles/display at DL-2.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.4468	0.5689	0.3622	0.1594	0.1077	0.1019	0.0674	0.0748	0.0490
0.0177	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.5177	0.6591	0.4196	0.1801	0.1227	0.1162	0.0772	0.0857	0.0563
0.0185	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-9
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 8 cycles/display at DL-3.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.1189	0.1514	0.0964	0.0480	0.0311	0.0293	0.0189	0.0211	0.0135
0.0977	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.1973	0.2512	0.1599	0.0772	0.0506	0.0477	0.0309	0.0345	0.0222
0.0988	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.2730	0.3476	0.2213	0.1038	0.0687	0.0648	0.0423	0.0471	0.0305
0.1005	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-9 Continued
Displayed Luminance modulations for the fundamental frequency (F_1) and harmonics for 1-D, 8 cycles/display at DL-3.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4 / a_0	Displayed Luminance Modulation	0.3775	0.4806	0.3060	0.1380	0.0925	0.0875	0.0575	0.0639	0.0417
0.1081	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5 / a_0	Displayed Luminance Modulation	0.4428	0.5638	0.3589	0.1581	0.1068	0.1011	0.0668	0.0742	0.0485
0.1113	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-10
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 8 cycles/display at DL-1.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.3222	0.4103	0.2612	0.1203	0.0801	0.0757	0.0495	0.0551	0.0358
0.0161	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.4400	0.5602	0.3566	0.1573	0.1062	0.1005	0.0664	0.0738	0.0482
0.0195	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.6424	0.8179	0.5207	0.2142	0.1478	0.1403	0.0941	0.1042	0.0689
0.0205	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-10 Continued
Displayed Luminance modulations for the fundamental frequency (F_1) and harmonics for 2-D, 8 cycles/display at DL-1.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.7423	0.9451	0.6017	0.2395	0.1670	0.1586	0.1072	0.1184	0.0788
a_0 0.0230	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Modulation	0.8296	1.0000	0.6725	0.2603	0.1830	0.1740	0.1183	0.1305	0.0872
a_0 0.0285	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-11
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 8 cycles/display at DL-2.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1 a_0 0.0615	Displayed Luminance Modulation	0.2877	0.3663	0.2332	0.1088	0.0721	0.0681	0.0445	0.0495	0.0321
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2 a_0 0.0668	Displayed Luminance Modulation	0.3973	0.5058	0.3220	0.1442	0.0969	0.0917	0.0604	0.0671	0.0438
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3 a_0 0.0687	Displayed Luminance Modulation	0.5899	0.7510	0.4781	0.2002	0.1374	0.1303	0.0871	0.965	0.0636
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-11 Continued
Displayed Luminance modulations for the fundamental frequency (F_1) and harmonics for 2-D, 8 cycles/display at DL-2.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.6848	0.8719	0.5551	0.2251	0.1561	0.1482	0.0997	0.1103	0.0731
0.0819	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.7791	0.9920	0.6315	0.2484	0.1738	0.1652	0.1119	0.1236	0.0824
0.0972	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-12
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 8 cycles/display at DL-3.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5f_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.3027	Displayed Luminance Modulation	0.2345	0.2985	0.1900	0.0905	0.0596	0.0562	0.0365	0.0407	0.0263
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0 0.3208	Displayed Luminance Modulation	0.3273	0.4167	0.2653	0.1219	0.0812	0.0767	0.0503	0.0559	0.0363
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0 0.3224	Displayed Luminance Modulation	0.5004	0.6371	0.4056	0.1751	0.1190	0.1128	0.0749	0.0830	0.0545
	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-12 Continued
Displayed Luminance modulations for the fundamental frequency (F_1) and harmonics for 2-D, 8 cycles/display at DL-3.

Frequency		F_1 (0.2287)			$3F_1$ (0.6861)		$5F_1$ (1.143)		$7F_1$ (1.601)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.5961	0.7589	0.4832	0.2018	0.1387	0.1315	0.0879	0.0974	0.0643
0.3428	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.6926	0.8818	0.5614	0.2271	0.1576	0.1496	0.1007	0.1114	0.0739
0.5875	CTF value	0.0090	0.0090	0.0090	0.0070	0.0070	0.0070	0.0070	0.0077	0.0077
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-13
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-1.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.1638	0.2085	0.1327	0.0648	0.0422	0.0397	0.0256	0.0283	0.0182
0.0033	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.2641	0.3362	0.2140	0.1005	0.0664	0.0624	0.0407	0.0448	0.0290
0.0034	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.3512	0.4472	0.2847	0.1293	0.0864	0.0813	0.0534	0.0588	0.0382
0.0035	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-13 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-1.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Amplitude	0.4925	0.6270	0.3992	0.1724	0.1171	0.1104	0.0732	0.0805	0.0528
a_0 0.0039	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Amplitude	0.5700	0.7258	0.4620	0.1942	0.1330	0.1256	0.0838	0.0920	0.0606
a_0 0.0042	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-14
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-2.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0154	Displayed Luminance Modulation	0.1453	0.1850	0.1178	0.0579	0.0376	0.0353	0.0228	0.0252	0.0162
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0 0.0157	Displayed Luminance Modulation	0.2351	0.2993	0.1906	0.0904	0.0595	0.0560	0.0364	0.0401	0.0259
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0 0.0161	Displayed Luminance Modulation	0.3222	0.4102	0.2612	0.1199	0.0798	0.0751	0.0492	0.0542	0.0352
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-14 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-2.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Amplitude	0.4468	0.5689	0.3621	0.1589	0.1074	0.1012	0.0669	0.0736	0.0481
a_0 0.0177	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Amplitude	0.5176	0.6591	0.4196	0.1796	0.1223	0.1154	0.0767	0.0843	0.0554
a_0 0.0185	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-15
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-3.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0977	Displayed Luminance Modulation	0.1189	0.1514	0.0964	0.0479	0.0310	0.0291	0.0187	0.0207	0.0133
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0 0.0988	Displayed Luminance Modulation	0.1973	0.2512	0.1599	0.0770	0.0504	0.0474	0.0307	0.0339	0.0218
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0 0.1005	Displayed Luminance Modulation	0.2730	0.3475	0.2212	0.1035	0.0685	0.0644	0.0420	0.0463	0.0300
	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-15 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 16 cycles/display at DL-3.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Amplitude	0.3774	0.4805	0.3059	0.1376	0.0922	0.0869	0.0571	0.0629	0.0410
a_0										
0.1081	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Amplitude	0.4427	0.5637	0.3589	0.1577	0.1065	0.1004	0.0663	0.0730	0.0477
a_0										
0.1113	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-16
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-1.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.3222	0.4102	0.2612	0.1199	0.0798	0.0751	0.0492	0.0542	0.0352
0.0161	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.4399	0.5601	0.3566	0.1569	0.1059	0.0998	0.0660	0.0726	0.0474
0.0195	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.6423	0.8178	0.5206	0.2136	0.1474	0.1394	0.0935	0.1025	0.0678
0.0205	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-16 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-1.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Amplitude	0.7422	0.9450	0.6016	0.2389	0.1665	0.1576	0.1064	0.1166	0.0755
0.0230	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5										
a_0	Displayed Luminance Amplitude	0.8295	1.0000	0.6724	0.2597	0.1826	0.1730	0.1175	0.1285	0.0858
0.0285	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-17
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-2.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance Modulation	0.2877	0.3663	0.2332	0.1085	0.0719	0.0676	0.0441	0.0487	0.0315
a_0 0.0615	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
2	Displayed Luminance Modulation	0.3972	0.5058	0.3220	0.1438	0.0966	0.0910	0.0599	0.0660	0.0430
a_0 0.0668	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3	Displayed Luminance Modulation	0.5898	0.7510	0.4781	0.1996	0.1370	0.1294	0.0865	0.0949	0.0626
a_0 0.0687	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-17Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-2.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Amplitude	0.6847	0.8718	0.5550	0.2245	0.1556	0.1472	0.0990	0.1085	0.0719
0.0819	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Amplitude	0.7790	0.9919	0.6315	0.2478	0.1734	0.1642	0.1111	0.1217	0.0810
0.0972	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-18
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-3.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0	Displayed Luminance Modulation	0.2344	0.2985	0.1900	0.0902	0.0594	0.0558	0.0363	0.0400	0.0259
0.3027	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2, a_0	Displayed Luminance Modulation	0.3272	0.4166	0.2652	0.1216	0.0810	0.0762	0.0499	0.0550	0.0357
0.3208	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0	Displayed Luminance Modulation	0.5003	0.6370	0.4055	0.1746	0.1187	0.1120	0.0743	0.0817	0.0536
0.3224	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-18 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 16 cycles/display at DL-3.

Frequency		F_1 (0.4575)			$3F_1$ (1.372)		$5F_1$ (2.287)		$7F_1$ (3.202)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Amplitude	0.5960	0.7589	0.4831	0.2013	0.1383	0.1306	0.0873	0.0958	0.0632
a_0 0.3428	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance Amplitude	0.6925	0.8817	0.5613	0.2265	0.1571	0.1486	0.1000	0.1096	0.0727
a_0 0.3875	CTF value	0.0074	0.0074	0.0074	0.0073	0.0073	0.0090	0.0090	0.0112	0.0112
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-19
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-1.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0033	Displayed Luminance Modulation	0.1635	0.2082	0.1325	0.0640	0.0417	0.0382	0.0247	0.0264	0.0169
	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude 2, a_0 0.0034	Displayed Luminance Modulation	0.2636	0.3357	0.2137	0.0992	0.0655	0.0602	0.0392	0.0418	0.0270
	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3, a_0 0.0035	Displayed Luminance Modulation	0.3507	0.4465	0.2843	0.1278	0.0853	0.0785	0.0515	0.0549	0.0357
	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-19 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-1.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4										
a_0	Displayed Luminance Modulation	0.4917	0.6261	0.3986	0.1705	0.1157	0.1067	0.0707	0.0753	0.0493
0.0039	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u>										
5										
a_0	Displayed Luminance Modulation	0.5691	0.7247	0.4613	0.1921	0.1315	0.1215	0.0809	0.0861	0.0566
0.0042	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-20
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-2.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u> 1										
a_0	Displayed Luminance Modulation	0.1451	0.1847	0.1176	0.0572	0.0372	0.0340	0.0219	0.0235	0.0151
0.0154	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
<u>Amplitude</u> 2										
a_0	Displayed Luminance Modulation	0.2347	0.2989	0.1903	0.0893	0.0588	0.0540	0.0350	0.0374	0.0242
0.0157	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	no
<u>Amplitude</u> 3										
a_0	Displayed Luminance Modulation	0.3217	0.4096	0.2608	0.1185	0.0788	0.0725	0.0474	0.0506	0.0328
0.0161	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-20 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-2.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4	Displayed Luminance Modulation	0.4461	0.5680	0.3616	0.1571	0.1061	0.0978	0.0645	0.0688	0.0449
a_0 0.0177	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u>										
5	Displayed Luminance Modulation	0.5168	0.6581	0.4189	0.1776	0.1209	0.1116	0.0740	0.0789	0.0517
a_0 0.0185	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-21
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-3.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.1187	0.1511	0.0962	0.0473	0.0306	0.0280	0.0180	0.0193	0.0124
0.0977	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.1970	0.2508	0.1597	0.0761	0.0498	0.0457	0.0296	0.0316	0.0203
0.0988	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	no
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.2725	0.3470	0.2209	0.1022	0.0676	0.0621	0.0405	0.0432	0.0279
0.1005	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-21 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 32 cycles/display at DL-3.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 4 a_0 0.1081	Displayed Luminance Modulation	0.3768	0.4798	0.3055	0.1361	0.0911	0.0839	0.0551	0.0587	0.0382
	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 5 a_0 0.1113	Displayed Luminance Modulation	0.4421	0.5629	0.3583	0.1559	0.1052	0.0970	0.0640	0.0682	0.0445
	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-22
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-1.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.3217	0.4096	0.2608	0.1185	0.0788	0.0725	0.0474	0.0506	0.0328
0.0161	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2										
a_0	Displayed Luminance Modulation	0.4393	0.5593	0.3561	0.1551	0.1046	0.0964	0.0636	0.0678	0.0443
0.0195	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3										
a_0	Displayed Luminance Modulation	0.6413	0.8166	0.5198	0.2114	0.1458	0.1348	0.0902	0.0960	0.0633
0.0205	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-22 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-1.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.7411	0.9436	0.6007	0.2365	0.1647	0.1526	0.1028	0.1093	0.0725
0.0230	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.8283	1.0000	0.6714	0.2571	0.1806	0.1675	0.1136	0.1206	0.0803
0.0285	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-23
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-2.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.2872	0.3657	0.2328	0.1072	0.0710	0.0652	0.0425	0.0454	0.0294
0.0615	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 2										
a_0	Displayed Luminance Modulation	0.3966	0.5050	0.3215	0.1422	0.0954	0.0879	0.0578	0.0616	0.0401
0.0668	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude 3										
a_0	Displayed Luminance Modulation	0.5889	0.7498	0.4774	0.1975	0.1355	0.1252	0.0835	0.0889	0.0585
0.0687	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-23 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-2.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.6837	0.8705	0.5542	0.2222	0.1539	0.1424	0.0956	0.1017	0.0672
0.0819	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.7779	0.9904	0.6305	0.2453	0.1715	0.1590	0.1074	0.1141	0.0758
0.0972	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-24
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-3.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.2341	0.2980	0.1897	0.0891	0.0586	0.0538	0.0349	0.0373	0.0241
0.3027	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.3267	0.4160	0.2648	0.1201	0.0800	0.0735	0.0481	0.0513	0.0333
0.3208	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.4996	0.6360	0.4049	0.1727	0.1173	0.1082	0.0717	0.0764	0.0500
0.3224	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-24 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 32 cycles/display at DL-3.

Frequency		F_1 (0.9138)			$3F_1$ (0.3435)		$5F_1$ (0.5725)		$7F_1$ (0.8015)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4	Displayed Luminance									
a_0	Modulation	0.5951	0.7577	0.4824	0.1992	0.1367	0.1263	0.0843	0.0897	0.0590
0.3428	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes
<u>Amplitude</u>										
5	Displayed Luminance									
a_0	Modulation	0.6914	0.8803	0.5604	0.2242	0.1554	0.1438	0.0966	0.1027	0.0679
0.3875	CTF value	0.0069	0.0069	0.0069	0.0100	0.0100	0.0171	0.0171	0.0265	0.0265
	Detection	yes	yes	yes	yes	yes	yes	yes	yes	yes

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-25
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-1.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
1										
a_0	Displayed Luminance Modulation	0.1627	0.2072	0.1319	0.0607	0.0395	0.0331	0.0213	0.0200	0.0128
0.0033	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	no	no	no	no
<u>Amplitude</u>										
2										
a_0	Displayed Luminance Modulation	0.2624	0.3341	0.2127	0.0944	0.0622	0.0523	0.0340	0.0318	0.0205
0.0034	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
<u>Amplitude</u>										
3										
a_0	Displayed Luminance Modulation	0.3490	0.4444	0.2829	0.1218	0.0811	0.0684	0.0447	0.0419	0.0271
0.0035	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table 25 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-1.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4										
a_0	Displayed Luminance Modulation	0.4893	0.6230	0.3966	0.1627	0.1101	0.0934	0.0615	0.0578	0.0376
0.0039	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
<u>Amplitude</u>										
5										
a_0	Displayed Luminance Modulation	0.5664	0.7211	0.4591	0.1837	0.1253	0.1065	0.0705	0.0662	0.0432
0.0042	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-26
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-2.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.1443	0.1838	0.1170	0.0542	0.0352	0.0295	0.0190	0.0178	0.0114
0.0154	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.2336	0.2974	0.1893	0.0849	0.0558	0.0469	0.0303	0.0284	0.0183
0.0157	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.3201	0.4076	0.2595	0.1128	0.0749	0.0631	0.0411	0.0386	0.0249
0.0161	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-26 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-2.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.4439	0.5652	0.3598	0.1499	0.1009	0.0854	0.0561	0.0527	0.0342
0.0177	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.5143	0.6549	0.4169	0.1696	0.1151	0.0977	0.0645	0.0605	0.0394
0.0185	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-27
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-3.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0977	Displayed Luminance Modulation	0.1181	0.1504	0.0958	0.0448	0.0290	0.0243	0.0156	0.0146	0.0093
	CSF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude 2, a_0 0.0988	Displayed Luminance Modulation	0.1960	0.2496	0.1589	0.0722	0.0472	0.0396	0.0256	0.0240	0.0154
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude 3, a_0 0.1005	Displayed Luminance Modulation	0.2712	0.3453	0.2198	0.0973	0.0642	0.0540	0.0351	0.0329	0.0212
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-27 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 64 cycles/display at DL-3.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.3750	0.4775	0.3040	0.1297	0.0866	0.0732	0.0478	0.0449	0.0290
a_0 0.1081	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude										
5	Displayed Luminance Modulation	0.4399	0.5601	0.3566	0.1488	0.1001	0.0847	0.0557	0.0522	0.0339
a_0 0.1113	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-28
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-1.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0161	Displayed Luminance Modulation	0.3201	0.4076	0.2595	0.1128	0.0749	0.0631	0.0411	0.0386	0.0249
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
Amplitude 2, a_0 0.0195	Displayed Luminance Modulation	0.4371	0.5566	0.3543	0.1479	0.0995	0.0843	0.0553	0.0519	0.0337
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude 3, a_0 0.0205	Displayed Luminance Modulation	0.6382	0.8126	0.5173	0.2022	0.1390	0.1184	0.0788	0.0740	0.0484
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table 28 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-1.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.7375	0.9390	0.5978	0.2266	0.1572	0.1344	0.0899	0.0846	0.0555
0.0230	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.8242	1.0000	0.6681	0.2467	0.1725	0.1478	0.0995	0.0936	0.0617
0.0285	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table 29
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-2.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0615	Displayed Luminance Modulation	0.2858	0.3639	0.2317	0.1020	0.0674	0.0567	0.0369	0.0346	0.0223
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
Amplitude 2, a_0 0.0668	Displayed Luminance Modulation	0.3947	0.5025	0.3199	0.1355	0.0908	0.0767	0.0502	0.0471	0.0305
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude 3, a_0 0.0687	Displayed Luminance Modulation	0.5861	0.7462	0.4750	0.1888	0.1291	0.1098	0.0728	0.0684	0.0446
	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table 29 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-2.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.6803	0.8662	0.5515	0.2127	0.1468	0.1253	0.0835	0.0785	0.0515
a_0 0.0819	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude										
5	Displayed Luminance Modulation	0.7741	0.9856	0.6274	0.2352	0. 1637	0.1401	0.0940	0.0884	0.0581
a_0 0.0972	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-2(cd/m^2) or DC Value

Table A-30
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-3.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.2329	0.2966	0.1888	0.0847	0.0556	0.0467	0.0303	0.0284	0.0182
0.3027	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.3251	0.4140	0.2635	0.1144	0.0760	0.0640	0.0417	0.0391	0.0253
0.3208	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	no	no	no
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.4971	0.06330	0.4030	0.1649	0.1117	0.0947	0.0624	0.0586	0.0381
0.3224	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-30 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 64 cycles/display at DL-3.

Frequency		F_1 (0.2291)			$3F_1$ (0.6873)		$5F_1$ (1.1455)		$7F_1$ (1.604)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 4 a_0	Displayed Luminance Modulation	0.5922	0.7540	0.4800	0.1904	0.1303	0.1108	0.0735	0.0691	0.0451
0.3428	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no
Amplitude 5 a_0	Displayed Luminance Modulation	0.6881	0.8761	0.5577	0.2146	0.1482	0.1265	0.0844	0.0794	0.0520
0.3875	CTF value	0.0080	0.0080	0.0080	0.0200	0.0200	0.0464	0.0464	0.1111	0.1111
	Detection	yes	yes	yes	yes	yes	yes	yes	no	no

a_0 = Luminance at DL-3(cd/m^2) or DC Value

Table A-31
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-1.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.1591	0.2026	0.1289	0.0499	0.0323	0.0185	0.0118	0.0056	0.0035
0.0033	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 2										
a_0	Displayed Luminance Modulation	0.2565	0.3266	0.2079	0.0780	0.0511	0.0294	0.0189	0.0089	0.0057
0.0034	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
Amplitude 3										
a_0	Displayed Luminance Modulation	0.3412	0.4344	0.2766	0.1012	0.0669	0.0388	0.0250	0.0118	0.0076
0.0035	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-31 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-1.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.4784	0.6091	0.3877	0.1363	0.0913	0.0535	0.0347	0.0165	0.0106
0.0039	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.5537	0.7050	0.4488	0.1545	0.1042	0.0614	0.0400	0.0191	0.0122
0.0042	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-32
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-2.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.1411	0.1797	0.1144	0.0445	0.0288	0.0164	0.0105	0.0049	0.0031
0.0154	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.2284	0.2908	0.1851	0.0701	0.0458	0.0263	0.0169	0.0080	0.0051
0.0157	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.3130	0.3985	0.2537	0.0936	0.0617	0.0357	0.0230	0.0109	0.0069
0.0161	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-32 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-2.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.4340	0.5526	0.3518	0.1253	0.0836	0.0488	0.0316	0.0150	0.0096
a_0 0.0177	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude										
5	Displayed Luminance Modulation	0.5028	0.6402	0.4076	0.1423	0.0955	0.0561	0.0365	0.0173	0.0111
a_0 0.0185	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-33
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-3.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1 a_0 0.0977	Displayed Luminance Modulation	0.1155	0.1470	0.0936	0.0367	0.0237	0.0135	0.0086	0.0040	0.0026
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 2 a_0 0.0988	Displayed Luminance Modulation	0.1916	0.2440	0.1553	0.0595	0.0387	0.0222	0.0142	0.0067	0.0043
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 3 a_0 0.1005	Displayed Luminance Modulation	0.2651	0.3376	0.2149	0.0805	0.0528	0.0304	0.0196	0.0092	0.0059
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-33 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 128 cycles/display at DL-3.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.3666	0.4668	0.2972	0.1079	0.0715	0.0415	0.0268	0.0127	0.0081
0.1081	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.4301	0.5476	0.3486	0.1243	0.0829	0.0484	0.0314	0.0149	0.0095
0.1113	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-34
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-1.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
1										
a_0	Displayed Luminance Modulation	0.3130	0.3985	0.2537	0.0936	0.0617	0.0357	0.0230	0.0109	0.0069
0.0161	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
<u>Amplitude</u>										
2										
a_0	Displayed Luminance Modulation	0.4273	0.5441	0.3464	0.1236	0.0824	0.0481	0.0312	0.0148	0.0095
0.0195	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
<u>Amplitude</u>										
3										
a_0	Displayed Luminance Modulation	0.6239	0.7944	0.5057	0.1707	0.1159	0.0687	0.0448	0.0214	0.0137
0.0205	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-34 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-1.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
<u>Amplitude</u>										
4 a_0	Displayed Luminance Modulation	0.7209	0.9179	0.5844	0.1922	0.1315	0.0785	0.0515	0.0247	0.0159
0.0230	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
<u>Amplitude</u>										
5 a_0	Displayed Luminance Modulation	0.8058	1.0000	0.6531	0.2100	0.1448	0.0870	0.0572	0.0275	0.0177
0.0285	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-35
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-2.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1, a_0 0.0615	Displayed Luminance Modulation	0.2794	0.3558	0.2265	0.0844	0.0554	0.0320	0.0206	0.0097	0.0062
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
Amplitude 2, a_0 0.0668	Displayed Luminance Modulation	0.3858	0.4913	0.3128	0.1129	0.0750	0.0436	0.0282	0.0134	0.0085
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
Amplitude 3, a_0 0.0687	Displayed Luminance Modulation	0.5729	0.7295	0.4644	0.1590	0.1074	0.0634	0.0413	0.0197	0.0126
	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-35 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-2.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.6651	0.8468	0.5391	0.1800	0.1226	0.0729	0.0477	0.0228	0.0146
a_0 0.0819	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude										
5	Displayed Luminance Modulation	0.7567	0.9635	0.6134	0.1998	0.1372	0.0821	0.0539	0.0259	0.0166
a_0 0.0972	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-36
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-3.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.2277	0.2899	0.1846	0.0699	0.0457	0.0262	0.0168	0.0079	0.0051
0.3027	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 2										
a_0	Displayed Luminance Modulation	0.3179	0.4047	0.2576	0.0949	0.0626	0.0362	0.0234	0.0110	0.0071
0.3208	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	no	no	no	no	no
Amplitude 3										
a_0	Displayed Luminance Modulation	0.4860	0.6188	0.3939	0.1382	0.0926	0.0543	0.0353	0.0168	0.0107
0.3224	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-3 cd/m^2) or DC Value

Table A-36 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 128 cycles/display at DL-3.

Frequency		F_1 (0.4581)			$3F_1$ (1.3743)		$5F_1$ (2.290)		$7F_1$ (3.207)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.5790	0.7371	0.4693	0.1604	0.1084	0.0641	0.0417	0.0199	0.0128
0.3428	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.6727	0.8564	0.5452	0.1817	0.1238	0.0737	0.0482	0.0231	0.0148
0.3875	CTF value	0.0135	0.0135	0.0135	0.0767	0.0767	0.7000	0.7000	1.0000	1.0000
	Detection	yes	yes	yes	yes	yes	no	no	no	no

a_0 = Luminance at DL-3 cd/m^2) or DC Value

Table A-37
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-1.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude 1										
a_0	Displayed Luminance Modulation	0.1442	0.1835	0.1168	0.0211	0.0136	0.0046	0.0030	0.0010	0.0006
0.0033	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 2										
a_0	Displayed Luminance Modulation	0.2324	0.2959	0.1884	0.0336	0.0217	0.0075	0.0048	0.0016	0.0010
0.0034	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude 3										
a_0	Displayed Luminance Modulation	0.3092	0.3937	0.2506	0.0442	0.0286	0.0099	0.0063	0.0021	0.0013
0.0035	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-37 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-1.

Frequency		F_1 (0.9162)		$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)		
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.4335	0.5519	0.3514	0.0609	0.0397	0.0138	0.0088	0.0029	0.0018
0.0039	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.5017	0.6388	0.4067	0.0699	0.0456	0.0160	0.0102	0.0034	0.0021
0.0042	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-38
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-2.

Frequency		F_1 (0.9162)		$3F_1$ (2.749)	$5F_1$ (4.581)		$7F_1$ (6.413)			
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance									
a_0	Modulation	0.1279	0.1628	0.1036	0.0188	0.0120	0.0041	0.0026	0.0009	0.0005
0.0154	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2	Displayed Luminance									
a_0	Modulation	0.2069	0.2635	0.1677	0.0300	0.0193	0.0067	0.0042	0.0014	0.0009
0.0157	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3	Displayed Luminance									
a_0	Modulation	0.2836	0.3611	0.2299	0.0407	0.0263	0.0091	0.0058	0.0019	0.0012
0.0161	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0= Luminance at DL-2 (cd/m^2) or DC Value

Table A-38 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-2.

Frequency		F_1 (0.9162)	$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)			
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4										
a_0	Displayed Luminance Modulation	0.3933	0.5007	0.3188	0.0556	0.0361	0.0126	0.0080	0.0026	0.0017
0.0177	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5										
a_0	Displayed Luminance Modulation	0.4556	0.5801	0.3693	0.0639	0.0416	0.0145	0.0093	0.0031	0.0019
0.0185	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-39
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-3.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.1046	0.1332	0.0848	0.0154	0.0099	0.0034	0.0022	0.0007	0.0004
0.0977	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.1737	0.2211	0.1408	0.0253	0.0163	0.0056	0.0036	0.0012	0.0007
0.0988	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.2403	0.3059	0.1947	0.0347	0.0224	0.0077	0.0049	0.0016	0.0010
0.1005	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-39 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 1-D, 256 cycles/display at DL-3.

Frequency		F_1 (0.9162)	$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)			
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance Modulation	0.3322	0.4230	0.2693	0.0474	0.0307	0.0106	0.0068	0.0022	0.0014
a_0 0.1081	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5	Displayed Luminance Modulation	0.3897	0.4962	0.3159	0.0551	0.0358	0.0125	0.0080	0.0026	0.0017
a_0 0.1113	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0= Luminance at DL-3 (cd/m^2) or DC Value

Table A-40
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-1.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.2836	0.3611	0.2299	0.0407	0.0263	0.0091	0.0058	0.0019	0.0012
0.0161	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.3872	0.4931	0.3139	0.0548	0.0356	0.0124	0.0079	0.0026	0.0017
0.0195	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.5654	0.7199	0.4583	0.0780	0.0511	0.0180	0.0115	0.0038	0.0024
0.0205	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-40 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-1.

Frequency		F_1 (0.9162)		$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)		
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.6533	0.8318	0.5295	0.0891	0.0586	0.0207	0.0133	0.0044	0.0028
0.0230	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.7302	0.9297	0.5919	0.0985	0.0651	0.0231	0.0148	0.0049	0.0031
0.0230	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-1(cd/m^2) or DC Value

Table A-41
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-2.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1	Displayed Luminance Modulation	0.2532	0.3224	0.2052	0.0365	0.0236	0.0081	0.0052	0.0017	0.0011
a_0 0.0615	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2	Displayed Luminance Modulation	0.3496	0.4452	0.2834	0.0497	0.0322	0.0112	0.0072	0.0023	0.0015
a_0 0.0668	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3	Displayed Luminance Modulation	0.5192	0.6610	0.4208	0.0721	0.0471	0.0165	0.0106	0.0035	0.0022
a_0 0.0687	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-41 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-2.

Frequency		F_1 (0.9162)	$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)			
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.6027	0.7674	0.4885	0.0828	0.0543	0.0191	0.0123	0.0040	0.0026
0.0819	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.6857	0.8731	0.5558	0.0931	0.0613	0.0217	0.0139	0.0046	0.0029
0.0972	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-2 (cd/m^2) or DC Value

Table A-42
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-3.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
1										
a_0	Displayed Luminance Modulation	0.2064	0.2627	0.1673	0.0300	0.0193	0.0066	0.0042	0.0014	0.0009
0.3027	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
2										
a_0	Displayed Luminance Modulation	0.2880	0.3667	0.2335	0.0413	0.0267	0.0092	0.0059	0.0019	0.0012
0.3208	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
3										
a_0	Displayed Luminance Modulation	0.4404	0.5607	0.3570	0.0618	0.0403	0.0140	0.0090	0.0029	0.0019
0.3224	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-42 Continued
Displayed Luminance Modulations for the Fundamental Frequency (F_1) and Harmonics for 2-D, 256 cycles/display at DL-3.

Frequency		F_1 (0.9162)			$3F_1$ (2.749)		$5F_1$ (4.581)		$7F_1$ (6.413)	
Wave shape		Sine	Sq	Tri	Sq	Tri	Sq	Tri	Sq	Tri
Amplitude										
4	Displayed Luminance									
a_0	Modulation	0.5246	0.6680	0.4252	0.0728	0.0476	0.0167	0.0107	0.0035	0.0022
0.3428	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no
Amplitude										
5	Displayed Luminance									
a_0	Modulation	0.6095	0.7761	0.4941	0.0836	0.0549	0.0193	0.0124	0.0041	0.0026
0.3875	CTF value	0.0353	0.0353	0.0353	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Detection	yes	yes	yes	no	no	no	no	no	no

a_0 = Luminance at DL-3 (cd/m^2) or DC Value

Table A-43
Half-amplitudes (cd/m^2) for each A x DL x DIM condition.

DL	A	Half-Amplitude LuminaceValues (cd/m^2)		DC LuminanceValues (cd/m^2)	
		1-D	2-D	1-D	2-D
1	1	0.00055	0.00520	0.00335	0.01610
	2	0.00090	0.00860	0.00340	0.01950
	3	0.00125	0.01320	0.00355	0.02050
	4	0.00195	0.01715	0.00395	0.02305
	5	0.00240	0.02370	0.00420	0.02850
2	1	0.00225	0.01775	0.01545	0.06155
	2	0.00370	0.02660	0.01570	0.06680
	3	0.00520	0.04065	0.01610	0.06875
	4	0.00795	0.05625	0.01775	0.08195
	5	0.00960	0.07595	0.01850	0.09725
3	1	0.01165	0.07115	0.09775	0.30275
	2	0.01955	0.10525	0.09885	0.32085
	3	0.02750	0.16170	0.10050	0.32240
	4	0.04090	0.20485	0.10810	0.34285
	5	0.04940	0.26900	0.11130	0.38750

APPENDIX B

SUBJECT INSTRUCTIONS

Random Search Task- Day 1

In this experiment you will be presented with a map and symbols. You will be asked to search for a specified symbol on the map from among other symbols. At the beginning of each trial you will be presented with the prompt "READY, THE NEXT TARGET IS ______." This will be the target you will search for during that trial. The target will appear in only one position on the screen.

Examine the symbol and when you are ready to begin searching press the right button on the mouse input device. A map with symbols will be displayed to you. After you have located the target, press the left button on the mouse input device. A symbol identification (ID) number will appear to the right of each symbol, however, the symbols will be erased. Verbally report the symbol ID to the experimenter. The ID you report should correspond to the target you located.

During the course of this experiment please respond as **QUICKLY AND ACCURATELY** as possible, **BOTH ARE IMPORTANT.**

Your chair height and distance from the screen has been adjusted to your normal sitting position. Therefore, during the experiment please remain in your normal position and do not lean forward.

Throughout the experiment you will hear two tones. One tone will occur at the beginning of each trial with the READY prompt. This is to inform you that a trial will begin. Another tone will occur less frequently and is a prompt to the experimenter. You can ignore this tone.

On the first day of the experiment you will participate in 10 practice trials to become familiar with the procedure. There will be five sessions, one per day, and each session will last approximately two and one-half (2 1/2) hours. You will be given the opportunity to take short breaks at specified intervals.

Before beginning the experiment you will be given 5 minutes to become familiar with the symbols. Each symbol is presented on the screen. Many of the symbols are very similar, therefore, please note their differences. For example, for every symbol type, one symbol is drawn with all dots and another with missing dots (symbols 1 and 2). These should be considered as separate symbols. Also notice that diamonds are similar to circles (first eight symbols versus last four symbols). Please take 5 minutes to examine these symbols.

Random Search Task - Day 2-5

Thank you for your continuing participation in this experiment. As you may recall, you will be presented with a map and symbols. You will be asked to search for a specified symbol on the map from among other symbols. At the beginning of each trial you will hear a tone and be presented with the prompt "READY, THE NEXT TARGET IS ____". This will be the target you will search for during that trial. The target will appear in only one position on the screen.

Examine the symbol and when you are ready to begin searching press the right button on the mouse input device. A map with symbols will be displayed to you. After you have located the target, press the left button on the mouse input device. A symbol identification (D) number will appear to the right of each symbol, however, the symbols will be erased. Verbally report the symbol ID to the experimenter. The ID you report should correspond to the target you located.

Please remember to respond as **QUICKLY AND ACURATELY** as possible, **BOTH ARE IMPORTANT.**

Also remember not to lean forward but to remain in a normal seated position.

The session will again take approximately two and one-half (2 1/2) hours, but will be given the opportunity to take short breaks at specified intervals.

Before beginning the experiment, you will be given 5 minutes to refamiliarize yourself with the symbols and note again their differences. Take 5 minutes now to examine these symbols.

Magnitude Estimation Task - Day 1

In this study you will be presented with a series of stimuli in random order. At the beginning of each trial you will see the prompt "READY". A tone will indicate when the "READY" prompt is present. When you are ready, press the right button on the mouse input device and a stimulus will be presented.

For this task you will tell the experimenter how **uniform** the luminance on the display screen appears to you by assigning a number to the stimulus condition. A **Uniform** screen is one that is unchanging or unvarying in luminance across the screen. You are not rating how bright the screen is. Call the first stimulus any number that seems appropriate to you. Then assign successive numbers in such a way that they consistently reflect your subjective impression. For example, if a stimulus seems 20 times as **uniform** in luminance as the first stimulus, assign a number 20 times as large as the first. If it seems one-fifth as **uniform** in luminance, assign a number one-fifth as large and so forth. Use whole number, decimals, or fractions, but make each assignment as proportional to the **uniformity** of the screen as possible.

At times it may appear that there is no stimulus on the screen, however, one is present. Just estimate that screen accordingly. Also, occasionally you will hear an additional tone to that which tells you to begin a trial. This tone is a prompt to the experimenter and you may ignore it.

To begin you will participate in 10 practice trials to become familiar with the procedure. The session will last approximately two hours. You will be given the opportunity to take short breaks at specified intervals. Do you have any questions?

Magnitude Estimation Task - Day 2

Thank you for continuing your participation in this experiment. As you may recall you will be presented with stimuli on the screen and your task is to assign a number which reflects your subjective impression of how **uniform** (i.e., unchanging or unvarying) the luminance on the display screen appears to you. When the "READY" prompt is displayed, press the right button on the mouse input device and a stimulus will be presented.

Before beginning the experimental trials you will be shown examples of stimuli that you saw yesterday and you will be told what number you assigned. This is to remind you of the scale you were using. Press the right button on the mouse when you see the "READY" prompt and the stimulus will be displayed. After examining the stimulus, tell the experimenter when you are ready to see the next stimulus.

Do you have any questions?

APPENDIX C

PROCEDURE FOR TRANSFORMATION OF MAGNITUDE ESTIMATION DATA, AFTER KLING AND RIGGS (1971)

Step 1. Convert all scores to log 10.

Step 2. Take the mean of the log scores for the subjects' responses in each condition.

Step 3. Determine the mean of each individual subject's estimations across all condition levels.

Step 4. Determine the mean of all values obtained in Step 3. This is the log value of the grand mean of all responses.

Step 5. Subtract the mean obtained in Step 4 from each value obtained in Step 3.

Step 6. Subtract the values obtained in Step 5 from the values obtained in Step 2.

Step 7. Take the analog of the data obtained in Step 6.

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