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PHOTOMETRIC MEASUREMENT OF TARGET-BACKGROUND CONTRAST

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PHOTOMETRIC MEASUREMENT OF TARGET-BACKGROUND CONTRAST

INTRODUCTION

The Army has long been aware of the critical importance of surveillance activity in maximizing battlefield effectiveness. As a consequence, considerable effort has been directed toward developing a wide variety of surveillance systems. Surveillance system effectiveness is not simply a function of hardware component characteristics, but rather depends heavily on the performance of the human component. Thus, determination of human performance characteristics is necessary to adequately evaluate overall systems performance levels as well as to identify causal factors which contribute to suboptimal performance.

The Army Research Institute for the Behavioral and Social Sciences (ARI) has traditionally had a considerable interest in the evaluation of surveillance systems performance and has been particularly concerned with the performance of the human component under realistic operational conditions. In all surveillance systems the human component receives information about the tactical environment in either visual or auditory form, and most systems rely heavily on the observer's visual processes. For this reason the Army has recently been concerned with identifying and quantifying major variables affecting visual target detection performance of observers directly viewing a tactical scene (or remotely viewing a scene via a display). Effects of several major variables have been investigated (including observer-target range, sun-target-observer angle, angular target velocity, background complexity, and ambient illumination level) and some quantitative relations have been established.

In cases where such relations have been established, data can be provided for computer simulation models of visual target acquisition processes. Because the usefulness of computer models depends heavily on the completeness and accuracy of the parameters and weights employed, quantification of detection-related variables can contribute substantially to the Army's ability to predict accurately the combat effectiveness of surveillance activities.

One variable currently thought to play a central role in visual target acquisition processes is target-background brightness contrast. While various contrast effects have been explored in considerable detail in laboratory settings, few attempts have been made to evaluate the impact of brightness contrast on target acquisition in realistic tactical situations. Before this can be done, however, it is necessary to develop a system which yields valid and stable contrast measures in field contexts. Since the perception of target-background contrast is not determined solely by luminance differences between target and background, it is necessary to examine other factors which complexly determine perceived contrast. The purpose of this memorandum is to suggest some factors which may play important roles in the perception and estimation of target-background contrast and to present some preliminary data concerning contrast measurement using telephotometers.

FACTORS INFLUENCING PERCEIVED CONTRAST

LUMINANCE VS. BRIGHTNESS CONTRAST

It is important to distinguish between "luminance contrast" and "brightness contrast." The former term is used here to describe the degree to which two adjacent regions of the retina are differently illuminated: brightness contrast, on the other hand, represents the subjective dimension of luminance contrast and describes the perceived, or apparent, contrast. While luminance can be objectively measured using various instrumentation systems, brightness must be determined via subjective judgments of luminance magnitudes. Although brightness contrast is more relevant to the target detection problem than luminance contrast, the former is an elusive phenomenon and difficult to measure. It has been suggested, therefore, that luminance contrast be employed as an index of brightness contrast.

This approach has two major potential advantages: (1) measurements can be made via currently available instrumentation systems; (2) luminances can be determined objectively (and thus, presumabley, are precise and reliable--a point to be discussed below) obviating time-consuming, expensive, and complex subjective-response evaluation procedures.

Unfortunately, there are also drawbacks: brightness is determined by factors other than absolute luminance values, including overall ambient illumination level, glare, angular target size, and retinal location of the target image. Moreover, target and background brightnesses are partially determined by their spectral composition. That is, light of different wave lengths and equal intensity will appear to differ in brightness. These factors which may lead to differences between luminance and brightness contrasts are discussed below.

AMBIENT ILLUMINATION

The overall level of illumination is a critical determinant of brightness contrast. Under most circumstances, target and background reflectances are constant under varying illumination conditions. Thus, the target-background luminance ratio (luminance contrast), $\Delta L/L$, will be invariant regardless of illumination level. Brightness contrast, on the other hand, under low illumination is a direct function of illumination level. It is a common experience when reading in the evening to switch on a light when the brightness contrast between the print and page is sufficiently reduced to make reading difficult.

In general, brightness discrimination thresholds decrease with increasing retinal illumination levels. That is, considering only low to moderate levels, the greater the ambient illumination, the smaller the magnitude of minimum perceptible differences in luminance between stimuli. Jameson and Hurvich have found a similar relation between brightness contrast at higher illumination levels: brightness contrast increases with increasing illumination.[1] There is little doubt that uncorrected luminance contrast does not accurately reflect brightness contrast at low illumination levels. Luminance contrast data may be mathematically corrected, however, to be more representative of brightness contrast under these conditions. This procedure is a prerequisite for accurately estimating the influence of target-background brightness contrast on visual target detection during dawn and dusk illumination periods.

GLARE

Under conditions of high ambient illumination another factor which affects brightness contrast but not luminance contrast becomes important. Glare has long been recognized as a major determinant of brightness contrast.[2] The term "glare" is used here in a broad sense including the effects of any strong source of illumination (other than the target) and refractive atmospheric effects. It is not surprising that the closer the glare source to the target or the more intense the source, the poorer will be the discrimination between luminances (the lower will be the brightness contrast). The importance of glare effects is easily appreciated by considering a detection problem in which targets are presented within a few degrees of the setting sun. Under this condition brightness contrast would probably deviate substantially from luminance contrast. The potential sources of glare are numerous and include bright portions of the terrain, sun, hazy atmospheric conditions, and under some circumstances, artificial illumination. Clearly, the analysis of glare effects in field contexts is a complex affair since there are many potential types of glare sources, several of which may be present in different magnitudes, at different angular distances from the target, in a given situation. Under even moderate glare conditions, it is likely that luminance contrast would not be an accurate index of brightness contrast.

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[1] Jameson, D. and Hurvich, L. M. Complexities of perceived brightness. Science, 1961, 133, 174-179.

[2] Heineman, E. G. Simultaneous brightness induction. In Jameson, D. and Hurvich, L. M. (Eds.), Handbook of Sensory Physiology VII/pt.4: Visual Psychophysics. New York: Springer-Verlag, 1972.

ANGULAR TARGET SIZE

Angular target size also has an effect on brightness contrast. Under a variety of conditions the visual system has its peak sensitivity at intermediate spatial frequencies (angular sizes of light-dark alternation) of about 5 cycles/degree with decreased sensitivity at either higher or lower frequencies.[3,4] Sensitivity to brightness differences declines more gradually at low spatial frequencies than at high frequencies, where contrast factors interact heavily with visual acuity. Assuming that sensitivity to brightness contrast begins to fall off rapidly at about 0.2 cycle/minute of arc, and that a target is about 35 cm wide, brightness contrast should decrease sharply at ranges greater than 425 meters even though luminance contrast would remain unaffected by angular target size. This effect probably becomes practically important when targets subtend less than about 2 minutes of arc at the observer's position. That is, a target less than 35 cm in size presented at 600 meters will appear to have substantially less contrast than will be indicated by the luminance contrast index. Thus, luminance indices should be corrected to compensate for this effect when targets of small angular size are employed.

RETINAL LOCATION OF TARGET IMAGE

While the target image will be foveally projected (i.e., projected on dense central part of the retina) during recognition, identification, and location phases of the target acquisition process, the image will often be projected on the retinal periphery during the first instant of detection. Because of this, peripheral rather than foveal brightness contrast may be closely related to the probability of target detection. The sensitivity to brightness difference for targets of small to moderate angular size is a function of visual acuity, which is considerably poorer in the periphery that the fovea due to the relatively low density of peripheral retinal receptors.[5,6] Thus, for targets subtending small to moderate visual arcs, peripheral brightness contrast is substantially lower than foveal contrast, and only remotely related to luminance contrast. In addition, it should be noted that peripheral and foveal brightness contrast perceptions interact differentially with illumination level, since peripheral receptors are more

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[3] Campbell, F. W. and Gubish, R. W. Optical quality of the human eye. Journal of Physiology (London), 1956, 186, 558-578.

[4] Shade, O. H. Optical and photoelectric analog of the eye. Journal of the Optical Society of America, 1956, 46, 721-739.

[5] Osterberg, G. H. Topography of the layer of rods and cones in the human retina. Acta Opthalmology, Supplement IV, 1935.

[6] Jones, L. A. and Higgins, G. C. Photographer granularity and graininess, III. Some characteristics of the visual system of importance in the evaluation of graininess and granularity. Journal of the Optical Society of America, 1947, 37, 217-263.

sensitive than foveal receptors and also have different spectral sensitivity characteristics.[7] These factors will undoubtedly complicate the analysis of the effects of retinal target image location on the detection process.

SPECTRAL CHARACTERISTICS

The relative brightness of target and background are partially dependent on their spectral (color) compositions. For example, if target images of equal luminances are projected on the fovea, a green target will appear brighter than a blue target under photopic conditions. The fovea has a maximum efficiency at wavelengths around 550 nm (yellow-green) and decreasing efficiency at both longer (red) and shorter (blue) wavelengths with the result that, given equal luminance targets, a yellow-green target will generally appear brightest.[8] Thus, luminance contrast may tend to either under- or over-estimate brightness contrast depending on the relative spectral compositions and luminances of the target and background. For example, assume that a yellow-green target reflecting light centered at about a 550 nm wavelength is presented against a yellow field reflecting light centered at about 600 nm. Recalling that photopic (foveal) efficiency is greatest at 550 nm, luminance contrast would tend to overestimate brightness contrast if the background luminance was substantially greater than the target luminance. Conversely, luminance contrast would tend to underestimate brightness contrast if the target and background described above were of similar luminance. In addition, visual system spectral response characteristics interact with illumination level: the visual peak sensitivity changes from about 550 nm to almost 500 nm as illumination decreases from photopic to very low (scotopic) illumination levels.

EXPLORATORY TESTS

Considered separately, each of these visual system effects has an influence on the perception of brightness contrast. Taken together, they probably contribute heavily to divergence between luminance and brightness contrasts. The point is essentially a practical one and depends on the required estimation accuracy. It may be feasible to use luminance contrast to classify brightness contrasts into categories of, for example, high, medium, and low.

Several methods can potentially be used to measure luminance contrast, including photographic, photometric, and video techniques. The use of

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[7] Wright, W. D. The Measurement of Colour. New York: MacMillian, 1958.

[8] Graham, C. H. Discriminations that depend on wavelength. In Graham, C. H. (Ed.) Vision and Visual Perception, 1965, 350-369.

photometers showed some promise in this regard as these instruments are commonly used in laboratory situations to measure luminance characteristics of stimuli. Moreover, photometers yield timely, on-line measures of luminance while the other methods do not. Whether or not photometers could be used effectively in a field situation is a question which has not previously been adequately explored. In order to evaluate the degree to which luminance contrast approximates brightness contrast and to assess measurement reliability, a measurement system employing telephotometers was tested by the U.S. Army Combat Developments Experimentation Command (USACDEC)[9] and ARI. The goal of these exploratory tests was to provide "best case" data on the measurement system in a realistic field situation. To this end, only newly laboratory-calibrated photometers were used, performance of device operators was closely monitored, and only very high and very low target-background brightness contrast situations were used.

METHOD

Instrumentation. Three Gamma Model 2000 telephotometers[10] with support equipment were set up on a test site, so that photometers were as close to one another as possible. These instruments were capable of measuring luminances of areas of the following angular diameters: 2', 6', 20', 1°, and 3°.

Two photometer operators were assigned to each instrument. One operator was primarily responsible for aiming the instrument, the other for reading the luminance values indicated by the meter, making appropriate scale adjustments, and calibrating the instrument.

Design and Procedures. Tests were designed to alternately maximize and minimize subjectively judged target-background contrast. Two military officers and one civilian scientist agreed upon one high and one low contrast target location at a near range (approximately 200 meters), and at a mid-range (approximately 700 meters). Both low-contrast personnel

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[9] USACDEC had been tasked to provide data on the effects of apparent target-background contrast on target detection as a portion of the Army Small Arms Requirements Study (ASARS). ARI provided scientific support for ASARS II, Phase II, and because of a long-standing interest in target acquisition processes, became heavily involved in the evaluation of photometric indices of brightness contrast. (See: Army Small Arms Requirement Study II, Experiment FC008A, Final Report, Phase II, U.S. Army Combat Developments Experimentation Command, Fort Ord, California 93941, February 1975.)

[10] Commercial designations are used only for precision in describing the tests. Use does not constitute endorsement by the Army or by the US Army Research Institute for the Behavioral and Social Sciences.

targets were placed against backgrounds of very dense vegetation so that target and background had similar brightness. Conversely, high-contrast personnel targets were placed in open fields such that target and background brightness were as different as possible. Thus, two "ideal" contrast situations (one high and one low) were established at each of two ranges. Target personnel were placed at similar distances from the observation post at each range. Near-range tests were performed in the morning hours (0900-1200) and mid-range tests during the afternoon (1300-1500).

Target personnel were initially positioned in the near range, high contrast location directly facing the observation post and were directed to stand at attention until the completion of a measurement. Photometer operators then aimed their instruments at the target's mid-chest using a 2' aperture and indicated when they had the target properly sighted. After all three operators indicated they were ready, the command "mark" was given and the second operator recorded the luminance value. Following the measurements of target luminance, operators switched to a 1° aperture and, using the same aiming point, measured the background luminance using the same procedure. Thus, luminances from all three photometers were recorded simultaneously.

The target then moved to the low-contrast location and stood at attention. Photometer operators repeated the procedures outlined above. Throughout the testing, targets alternated between high and low contrast situations. Because the target changed positions following each target-background pair of measurements, it was necessary for the photometer operators to re-aim their instruments for each pair of measurements. Thus, the test was sensitive to telephotometer-aiming-error variability as well as error due to instrument instability, target and background (vegetation) movement, meter reading error, and various complex interactions of these factors.

Following completion of the test at the near range, tests were conducted at the mid-range using the same procedures except that a smaller aperture (20') was used for measurement of background luminance in order to exclude extraneous background and foreground material.

Photometers were recalibrated (internal calibration) at intervals no longer than 30 minutes.

RESULTS AND DISCUSSION

Twenty-seven low- and 27 high-contrast pairs of measurements were made in the near range, and 24 low- and 24 high-contrast pairs in the mid-range. (The smaller number of measurements at the mid-range was due to a malfunction of one telephotometer.) The target-background luminance contrast was calculated from the measured target and background luminances using the formula:

$$C_L = \frac{L_1 - L_2}{L_1}$$

where L_1 = the larger luminance value

L_2 = the smaller luminance value

C_L = the target-background luminance contrast.

Thus, indices could theoretically range from 0 (low contrast) to 1 (high contrast).

Figure 1 shows frequency distributions of contrast indices based on target and background luminance measurements at the near range. Distributions of contrast indices for extreme high and low contrast targets are clearly distinguishable. All low brightness contrast targets yielded contrast indices below 0.35 ($\bar{x}$ = .18); all but three high brightness contrast indices fell higher than 0.35 ($\bar{x}$ = .48). These data indicate that telephotometrically derived luminance contrast indices can be used to validly and reliably discriminate between very high and low brightness contrast at a relatively short range. Single measures of luminance contrast, however, would undoubtedly not accurately reflect intermediate levels of brightness contrast since the distributions of luminance contrast associated with extreme high and low brightness contrast targets overlap.

If the distribution statistics of luminance contrasts associated with intermediate brightness-contrast situations were determined, statistical methods (e.g., discriminative analysis) may be employed to categorize medium brightness contrast targets based upon luminance contrasts. Even finer discrimination is possible, though not necessarily practical, due to the large number of luminance measurements necessary to estimate distribution statistics.

Although measures of luminance contrast permit discrimination between high and low brightness contrast targets, the luminance contrast ($\bar{x}$ = .48) tends to considerably underestimate brightness contrast for high brightness contrast situations. It was initially expected that if luminance contrast approximated brightness contrast, luminance contrast for high contrast targets should be at least greater than 0.6.[11] It may be that "bright

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[11] U.S. Army Combat Developments Experimentation Command, Army Small Arms Requirements Study II, Project Analysis. Fort Ord, California 93941.

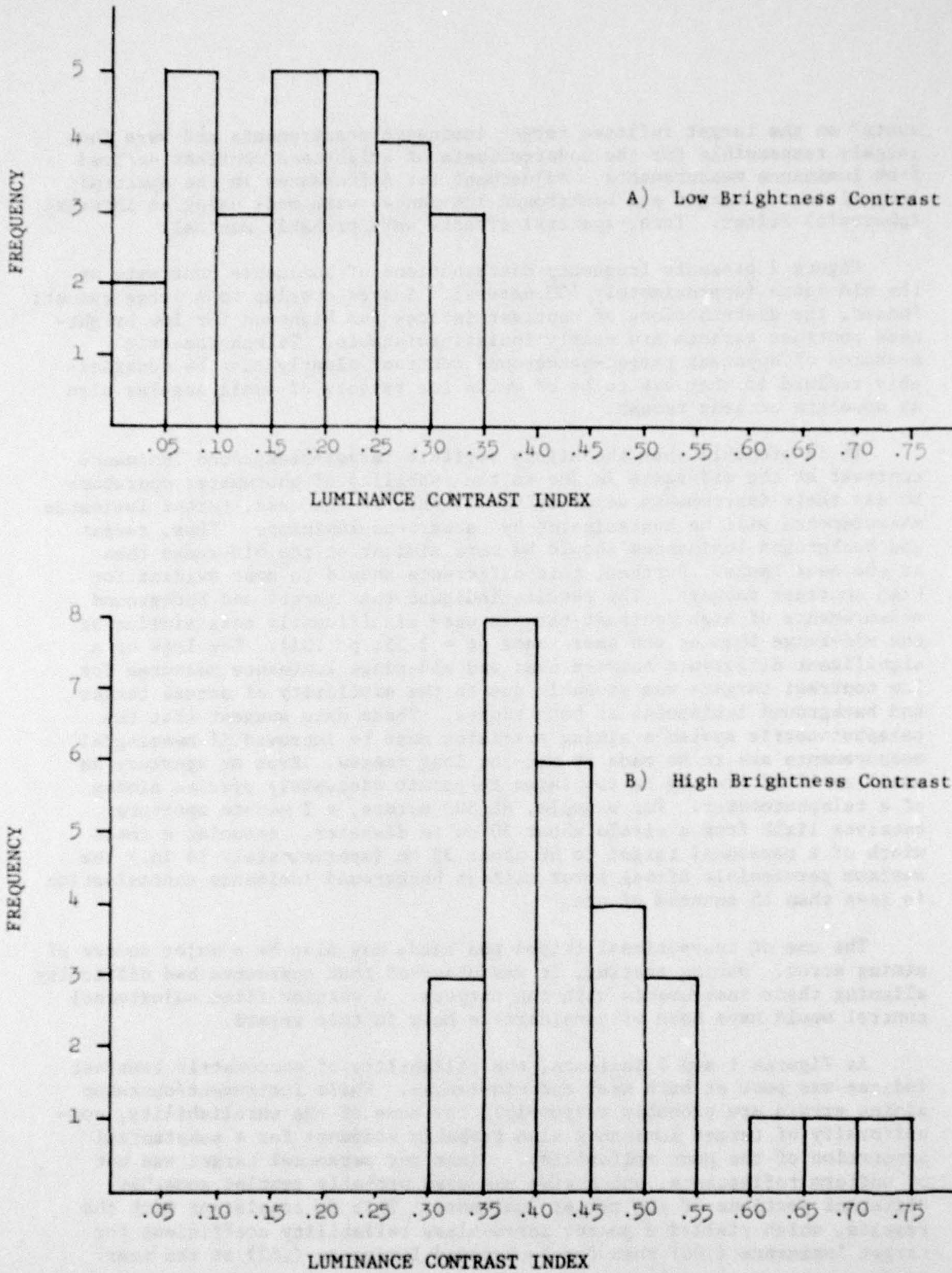

Figure 1. Frequency distributions of photometric target-background contrast indices; near range.

spots" on the target inflated target luminance measurements and were thus largely responsible for the underestimate of brightness contrast derived from luminance measurements. Adjustment for differences in the spectral composition of target and background luminances were made using an internal (photopic) filter. Thus, spectral effects were probably minimal.

Figure 2 presents frequency distributions of luminance contrasts at the mid-range (approximately 700 meters). Scores overlap to a large extent; indeed, the distributions of contrast indices for high and for low brightness contrast targets are nearly indistinguishable. Telephotometric measures of apparent target-background contrast clearly must be considerably refined if they are to be of value for targets of small angular size at moderate or long ranges.

It is probable that the highly variable target-background luminance contrast at the mid-range is due to the inability of photometer operators to aim their instruments accurately. If this is the case, target luminance measurements will be contaminated by background luminance. Thus, target and background luminances should be more similar at the mid-range than at the near range. Further, this difference should be most evident for high contrast targets. The results indicate that target and background measurements of high contrast targets were significantly more similar at the mid-range than at the near range ($t = 3.55$, $p < .01$). The lack of a significant difference between near and mid-range luminance measures for low contrast targets was probably due to the similarity of actual target and background luminances at both ranges. These data suggest that the telephotometric system's aiming precision must be improved if meaningful measurements are to be made at mid- or long ranges. Even an aperture as small as 2' of arc may be too large to permit adequately precise aiming of a telephotometer. For example, at 500 meters, a 2 minute aperture receives light from a circle about 30 cm in diameter. Assuming a chest width of a personnel target to be about 35 cm (approximately 14 in.) the maximum permissible aiming error without background luminance contamination is less than 15 seconds of arc.

The use of conventional tripod pan heads may also be a major source of aiming error. During testing, it was observed that operators had difficulty aligning their instruments with the targets. A vernier (fine adjustment) control would have been of considerable help in this regard.

As Figures 1 and 2 indicate, the reliability of photometric contrast indices was poor at both near and mid-ranges. While instrument/operator aiming errors are probably responsible for some of the unreliability, non-uniformity of target luminance also probably accounts for a substantial proportion of the poor reliability. Since any personnel target was not of uniform reflectance, successive measures probably sampled somewhat different portions of the target luminance. This is consistent with the results, which yielded a poorer intra-class reliability coefficient for target luminance (.06) than for background luminance (.62) at the near range.

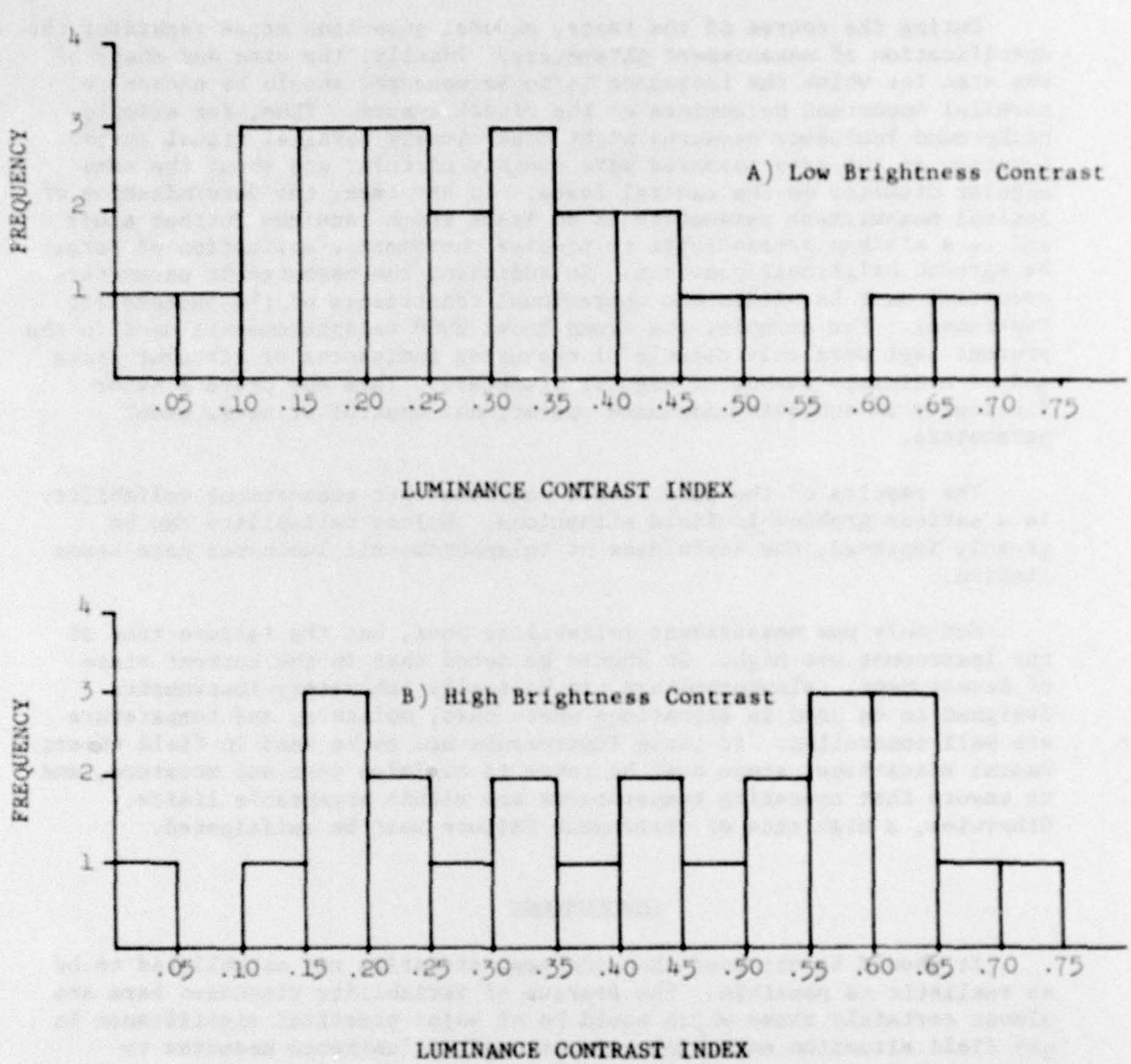

Figure 2. Frequency distribution of photometric target-background contrast indices; mid-range.

During the course of the tests, several questions arose regarding the specification of measurement parameters. Ideally, the size and shape of the area for which the luminance is to be measured should be chosen to parallel important parameters of the visual system. Thus, for example, background luminance measures might more closely parallel visual system function if the area measured were roughly circular and about the same angular diameter as the central fovea. In any case, the determination of optimal measurement parameters is an issue which requires further study and is a minimum prerequisite to precise photometric estimation of target-background brightness contrast. In addition, the measurement parameters specified must be within the operational constraints of the photometric instrument. For example, the Gamma Model 2000 telephotometers used in the present test were only capable of measuring luminances of circular areas and of a limited number of angular diameters. This may prove a major difficulty in achieving adequate operational control of measurement parameters.

The results of the pilot tests indicate that measurement reliability is a serious problem in field situations. Unless reliability can be greatly improved, the usefulness of telephotometric luminance data seems limited.

Not only was measurement reliability poor, but the failure rate of the instrument was high. It should be noted that in the current state of development, telephotometers are basically laboratory instruments designed to be used in situations where dust, moisture, and temperature are well controlled. If these instruments are to be used in field experimental situations, steps must be taken to minimize dust and moisture, and to ensure that operating temperatures are within acceptable limits. Otherwise, a high rate of instrument failure must be anticipated.

CONCLUSIONS

It should be stressed that the test situation was established to be as realistic as possible. The sources of variability discussed here are almost certainly those which would be of major practical significance in any field situation employing telephotometric luminance measures to estimate brightness.

The purpose of this memorandum has been to note some of the factors which may be important in estimating target-background brightness contrast. The factors mentioned are not intended to be exhaustive. Only those which were thought likely to have a major practical impact on brightness contrast estimation have been discussed. Other factors (e.g., angular target velocity) may also partially determine brightness contrast but may not be of practical significance. Clearly, accurate estimation of brightness contrast is a complex affair and requires considerable data in addition to luminance values. The relative importance of these factors should be determined in order to properly weight the luminance values obtained in various situations. Some of these (illumination level, spectral characteristics, and angular target size) may be susceptible to a fairly straightforward analysis, while others (glare and retinal location) are likely to require a concentrated and complex research effort.

In any case, the reliability of luminance measurement in field situations must be substantially improved if these measures are to be used as a basis for estimating brightness contrast. Moreover, the test results strongly suggest that if measures are to be made of small targets (e.g., personnel) at moderate to long ranges, some alterations to improve aiming accuracy will be necessary.

Finally, a luminance measurement system capable of reliably and accurately measuring luminances in operational situations should be developed. A variety of psychophysical techniques for determining perceived stimulus magnitudes are already available. If the impact of target-background brightness contrast on target acquisition is to be investigated, it will be necessary to determine the relation between brightness and luminance contrast in field contexts and also to determine the influence of other factors on this relation. It is suggested, therefore, that a research program be initiated to develop a measurement system capable of reliably and accurately estimating target-background brightness contrast.