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# Considerations and Standards for Visual Inspection Techniques

Gary T. Yonemura

Sensory Environment Section
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Institute for Applied Technology
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Considerations and Standards for Visual Inspection Techniques

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ABSTRACT: When we look at the capacity of the human visual system we see that man can adjust to a wide variety of operating conditions. But, unless we have detailed information on the conditions for which these processes are to be standardized and quantitative descriptions of the tasks to be performed, the advantages to be obtained by visual science applications cannot be optimally utilized. The Modulation Transfer Function would be an image evaluation technique applicable to NDT. Standardized tests to assess day to day performance as well as initial capacities should be developed. These tests should be derived from visual capacities correlated with the tasks to be performed.

KEY WORDS: Nondestructive inspection, vision tests, visual standards, visual performance.

In assessing the acceptability of mensurative techniques two basic uncertainty (reliability) measures are involved: 1. The repeatability of measurements with a given instrument, and 2. The agreement between different instruments or installations. Similar performance assessments leading to consistent performance should be required of visual techniques in nondestructive testing. One indication of this need may be the results of the Air Force round robin involving eleven installations as reported by Gulley [1]. The percentage of defects detected ran from a high of 93 to a low of 19 percent.

The performance of human observers in nondestructive testing (involving visual inspection) can be separated into two broad categories. The first involves detecting the inhomogeneity that may or may not be a defect. The second involves the interpretation of the inhomogeneity as being a fault or some artifact. To a large extent detection can be said to be dependent upon the physiological attributes of the observer and decision making, or interpretation, can be said to be for the most part a function of the cognition and experience of the observer. This dichotomy between physiological and cognitive attributes is not clear cut, as there are contributions of both to detection and interpretation.

In this presentation we will be discussing only the first problem: detection. Furthermore, we will be primarily interested in the problem of consistency of detection for the more difficult tasks. The fundamental measure is the probability of detection; detecting an inhomogeneity that may or may not be a defect. I would like to digress for a moment to describe the basic stimulus configuration used in most of the experiments whose results will be used to illustrate visual phenomena of interst to visual nondestructive inspection (NDI). In Fig. 1, (a) is the target to be detected seen against a background (b), (c) being the area surrounding the task. $\Delta L$ is the absolute value of the difference between the luminance of the target and its background. Contrast is defined as $\Delta L$ divided by the background luminance. In all of the experimental data shown, no attempt will be made to precisely describe the stimulus parameters. The purpose of these data is only to indicate the shape of the function.

As in any instrumental measurement technique our first concern is the consistency or repeatability of measurements with a given instrument. This concern should also hold for the human eye. Will the same inspector be able to detect targets of the same difficulty equally often at different times? Fig. 2 shows the results from a highly experienced observer obtained on two different days. The stimulus parameters were the same, the only observable difference being that the two curves were obtained 24 hours apart. Note that on day one this subject detected the target 80 percent of the time when there was a -0.18 log unit difference in the luminance between the target and background. On day two a -0.18 log unit difference was detected only 35 percent of the time. Also note that the variability in the response of this observer is about the same for day one and two, as indicated by the similarity in the slope of the two ogives. It has been the speaker's experience that data taken 1 or 2 hours apart are very similar, and do not manifest the changes that may occur over a 24 hour period. This type of performance is typically obtained from experienced observers in visual psychophysical experiments. An inexperienced observer will display a larger separation between the ogives, the separation decreasing with increases in experience. We see that even experienced observers display variability in visual capacities that may vary from day to day. This indicates the need for a test that the inspector can use to calibrate himself. "Calibrate," in the sense that he can determine whether he is performing at a prescribed performance level or better at that time. That is, he will not be ready to perform critical visual inspections, unless he can detect a target of predetermined size, contrast, luminance and blur. We will later discuss some variables that influence detection capacity and by following prescribed procedures, the inspector may be able to bring his performance to the required level. Of course, the above assumes the inspector has displayed a minimum visual sensory capacity as tested in NDI by physical examinations involving acuity tests.

No matter how consistent an inspector may be in repeating his performance day after day, unless his performance meets some minimum specified performance level his performance is unacceptable. An analogy in instrumental measurement arises in round robins conducted to assess consistency of measurements between laboratories and/or instruments. A given instrument in a given laboratory may give high repeatability time after time, but its measurements may be inconsistent with those from other laboratories. This second source of inconsistency in visual inspection techniques, is the variability between observers. In Fig. 3 we see the results for two different subjects obtained under identical conditions. One observer detects a -0.08 log unit difference about 70 percent of the time, whereas another subject can only detect this same difference 40 percent of the time. As stated earlier an appreciation of the need for standardizing this performance is indicated in NDI by the physical examinations involving acuity tests. An important question is: are we using the correct physical correlate to assess this performance?

Within and between observers inconsistency can be minimized by using more observers. Fig. 4 shows the results from an experiment where the performance of the group as a whole is presented. That is to say, at least one member of the group detected the target. For a single observer the probability of detection for a luminance level of 1.7 log luminance units is about 10 percent. When we double the number of observers, where now the probability of detection is based on at least one of two observers detecting the target, the percent detected increases to about 30 percent. With five observers the percent detected increases to 65 percent. We can bring percent detected to the 95 percent level by using ten observers. There is another important item of information that this set of curves tells us. As the number of observers is increased, the slope of the ogives becomes steeper. Since the slope of the ogive is a measure of the standard deviation or the variability of the data, we can also state that as the number of observers is increased, the consistency of the data increases. The writer fully realizes the impracticality of using ten observers to inspect the same sample. The data above were presented to give some indication of how consistency can be improved.

We saw that in standardizing the visual performance of nondestructive inspectors, we must consider within observers, between observers and between groups of observers' inconsistencies. The aim is to obtain as consistent a performance as possible using the human observer as the detector. The human visual system is a highly adaptive one. In Fig. 5 we see that the eye can, under the most optimum conditions, see a spot of light having a luminance less than $10^{-5}$ cd/m$^2$. The upper limit of visual tolerance or the pain threshold is about $10^5$ cd/m$^2$. The low to high range covers ten orders of magnitude or a ratio of 10 billion to 1. This large sensitivity range of the eye should not be construed as indicating that the eye is not sensitive to small changes. The eye can detect luminance changes as small as 1 percent.

What are some of the physical variables that may lead to inconsistencies in responding? I would like to state here that the variables to be discussed do not necessarily apply equally to the different nondestructive testing methods. A variable may be important for one technique but have little effect on another. For example, dark adaptation may be an important variable in x-radiography, but may be of less importance to liquid penetrant techniques. Fig. 6 gives the luminance level required to detect a spot of light against a dark background as a function of dark adaptation or time in the dark. The parameter is light adaptation or the luminance level to which the eye was adapted for 5 s previous to being dark adapted. It is obvious that after 5 min in the dark, the sensitivity of the eye is still differentially affected by the luminance level of the preadapting light. Even after 10 min the luminance level required to see the spot of light after preadapting to a photoflash is significantly greater than that required for the other light levels. For critical or more difficult tasks, the eye must be adapted for a longer period of time. For example, if the inspector just stepped in from the outdoors on a sunny day, he would be significantly less sensitive to the inspection task as opposed to having been in a dimly illuminated waiting room, before performing the inspection.

We obtain similar results by varying light adaptation duration rather than luminance levels of the adapting light. Fig. 7 is similar to Fig. 6, but in this case the adapting-light luminance was kept constant at 1060 $cd/m^2$ and the light adaptation period varied. We see that even after 10 min of dark adaptation, the luminance required to see a spot of light is significantly affected by the length of time the observer was light adapted prior to dark adaptation. For critical tasks even leaving the radiography room for 10 min to go to the rest room may significantly affect the ability to detect a hairline crack since the dark adapted state is quickly unadapted when the eye is exposed to light. The purpose of presenting these graphs is not only to describe the phenomena, but to indicate that in many cases we may have the relevant quantitative data, the remaining need being to determine the stimulus levels encountered in nondestructive testing.

Fig. 8 indicates that when working at threshold contrast levels, target detection can be improved by increasing the luminance level. For example, a target with log contrast of -0.5 cannot be detected at -1.0 log $cd/m^2$ but will be detected by increasing luminance level to 1.0 log $cd/m^2$. These numbers apply only for a target of specific size, in this case one subtending 40 min of arc, but the general form of the function applies to targets of all sizes. A word of caution: this sort of function applies to targets that can barely be detected. For targets with high contrast, such that they are easily observable, luminances above an optimum level may decrease the perceived contrast or the "goodness" of the target.

Fig. 9 shows the obvious: as the size of the target is increased, the luminance required to see a spot of light decreases. For NDI we will probably be more interested in the ability to detect targets with different contrast levels. Fig. 10 indicates that as target diameter decreases, contrast must be increased in order to detect the target. Note that in ND testing we will be dealing with the smaller sized targets, where there appears to be a linear relationship between angular subtense and log contrast.

These will be some of the variables that must be considered in standardizing the performance of ND inspectors, or at the least to optimize consistency of performance for a given inspector, performance between different inspectors and performance between groups of inspectors.

Several difficulties arise when we attempt to apply the data on the capacity of the human visual system to NDI techniques. When we looked at some examples of the capacity of the visual system we saw that it had a large responding range depending on the circumstances under which it was used. In fact, the data in any sensory field are data that describe how a given capacity is dependent on any one of a large number of variables. Any discussion on standardizing the sensory capacity of the human eye must be based on the circumstances under which this capacity is to be utilized. We must know that the eye is expected to see and the conditions under which the discriminations are to be made. We know considerably less of the demands made on the visual system by nondestructive inspection than we do of the limitations of the human eye. This deficiency is a serious one. We need quantitative measures describing the physical correlates of what the eye is expected to detect. For example: in radiography dimensional descriptions of the defect measured on the material has limited value in visual standards for NDI. The eye is asked to look at the radiograph, consequently the physical measure of interest is the defect as displayed on the film, regardless of how much it may differ from the actual defect. What is required are microdensitometric scanning measures of the defect taken directly from the radiograph. An analogous argument applies to liquid penetrants and magnetic particle inspections. Microphotometric scanning measures of the fluorescent indications will provide the necessary physical correlates required to completely describe the fluorescent indications as seen by the eye. Only then can we determine the capacity demanded of the eye and formulation meaningful standards leading to a more consistent defect detection probability within and between observers as well as between installations.

There does not seem to be much doubt that the primary visual parameters correlated with ND visual inspection tasks are contrast, size, luminance and blur. The question that remains is the magnitude of these parameters in NDI as discussed earlier. Time in almost all instances can be treated as infinite, as far as task description is concerned. The variables listed above are systematically treated by the concept of Modulation Transfer Function (MTF). We recommend that this concept be used in formulating NDI standards. An advantage is that the technique is currently being utilized in iptical evaluations, and many of the techniques developed can be transferred directly to NDI. MTF is already being used in medical radiography and is also being utilized in NDT for image enhancement techniques. The net effect of two variables can be treated as the product of the separate effects of the two variables on modulation, that is, contrast. In the writer's opinion, the ability of MTF to handle blur, an area which has been neglected in most applied visual problems, is in itself sufficient reason for using MTF.

In summarizing, we wish to suggest that the primary need is to collect quantitative data describing the stimuli that the eye has to detect. These data should preferably be in the form of microscanning which can be translated into MTF. The MTF of critical faults can serve as the minimum acceptable limits of detection capacity required from an observer and/or installation. These critical capacity requirements will form the basis from which standardized tests should be developed.

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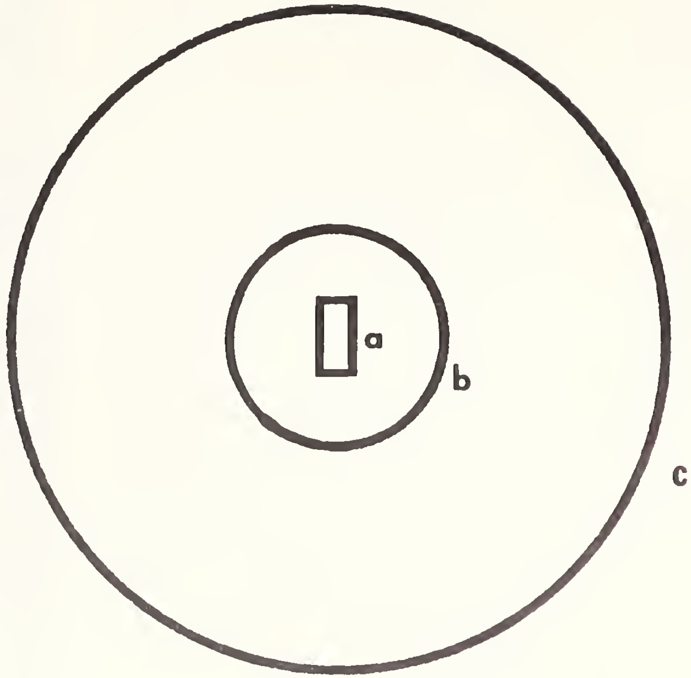


$$\Delta L = | L_a - L_b |$$

$$\text{CONTRAST} = \frac{\Delta L}{L_b}$$

FIG. 1 - Paradigm of stimulus configuration used to investigate contrast. (a) target (b) background (c) surround.

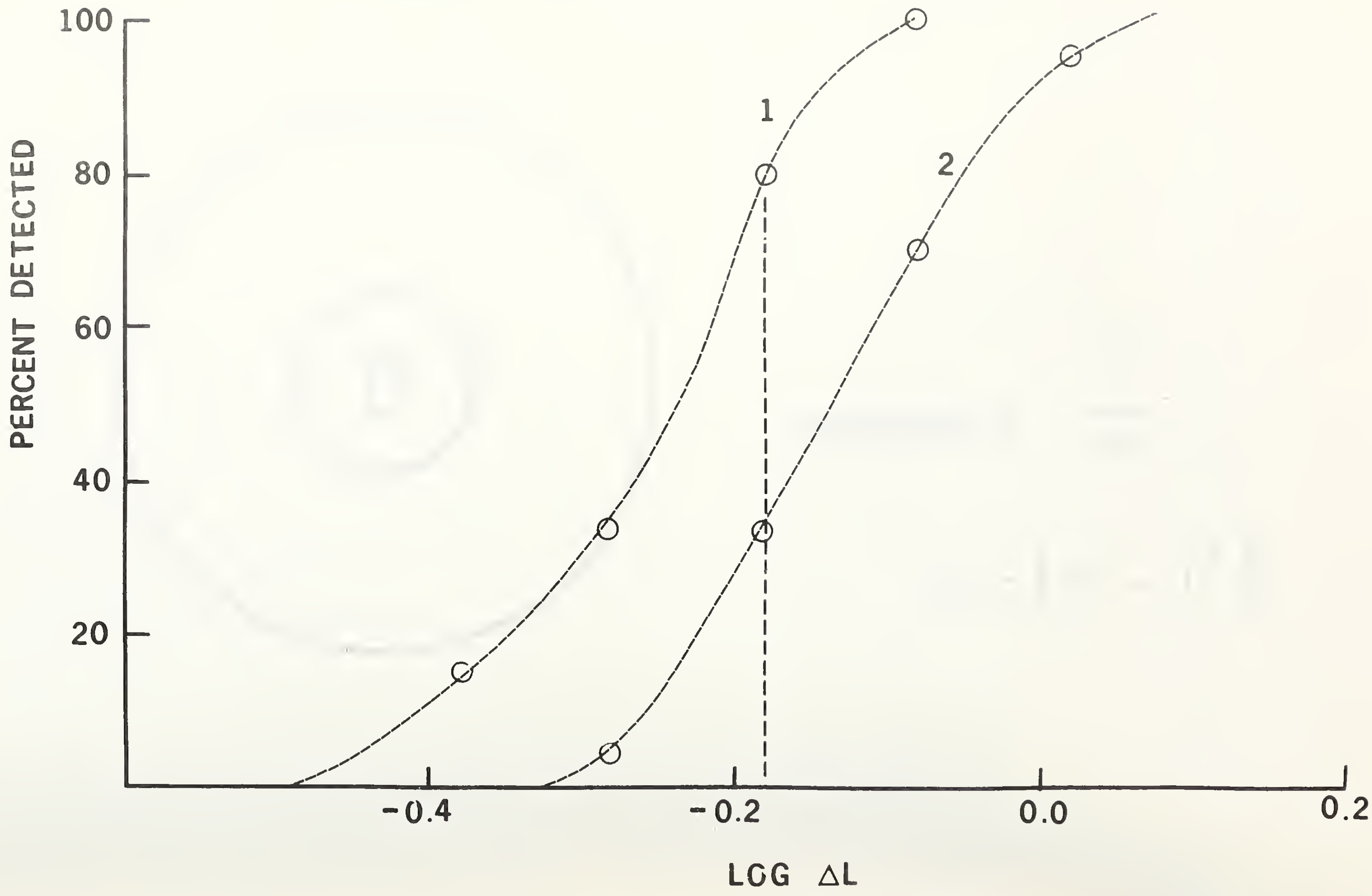


FIG. 2 - Individual variation from day to day. Adapted from Ref 2.

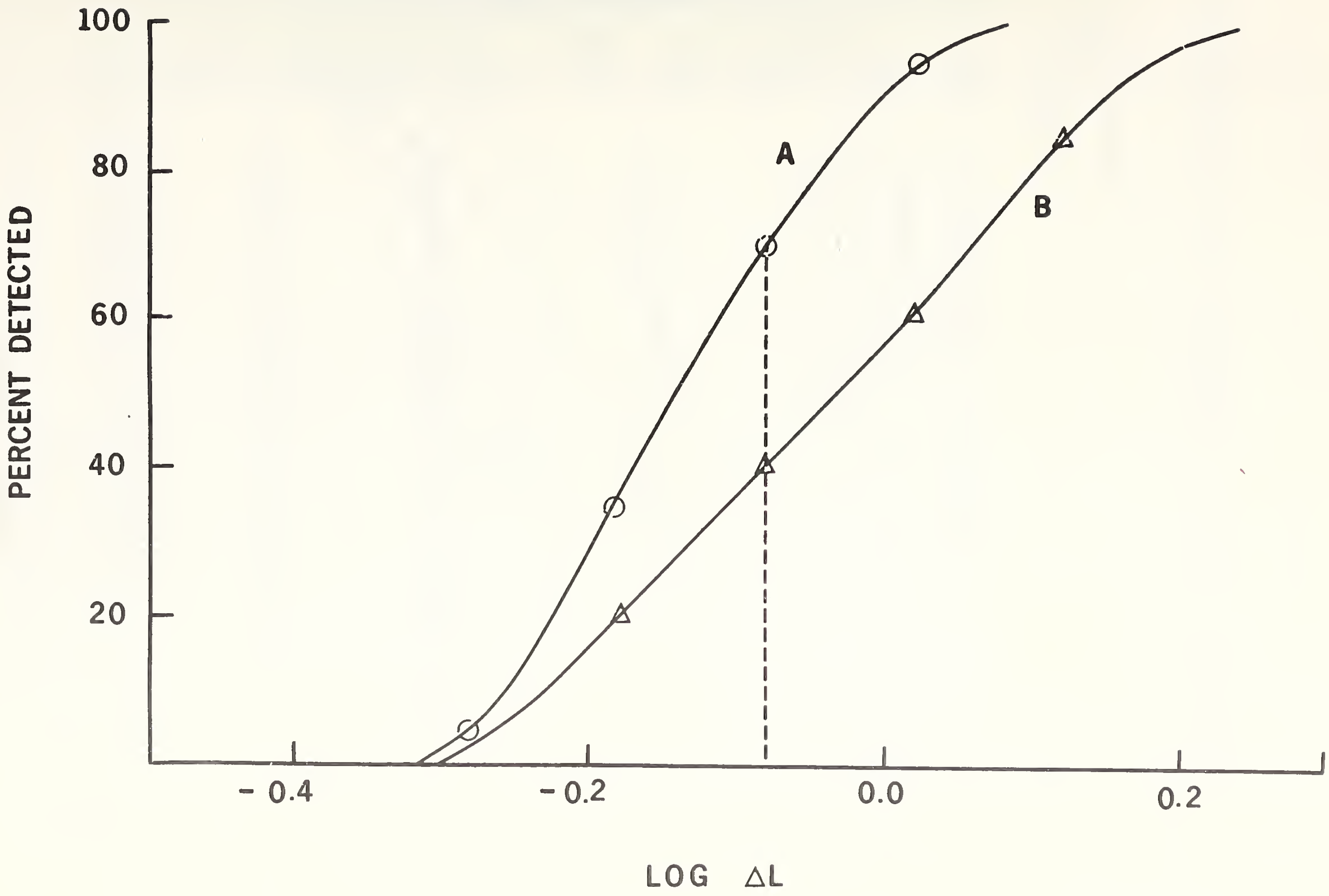


FIG. 3 - Variations between individuals. Adapted from Ref 2.

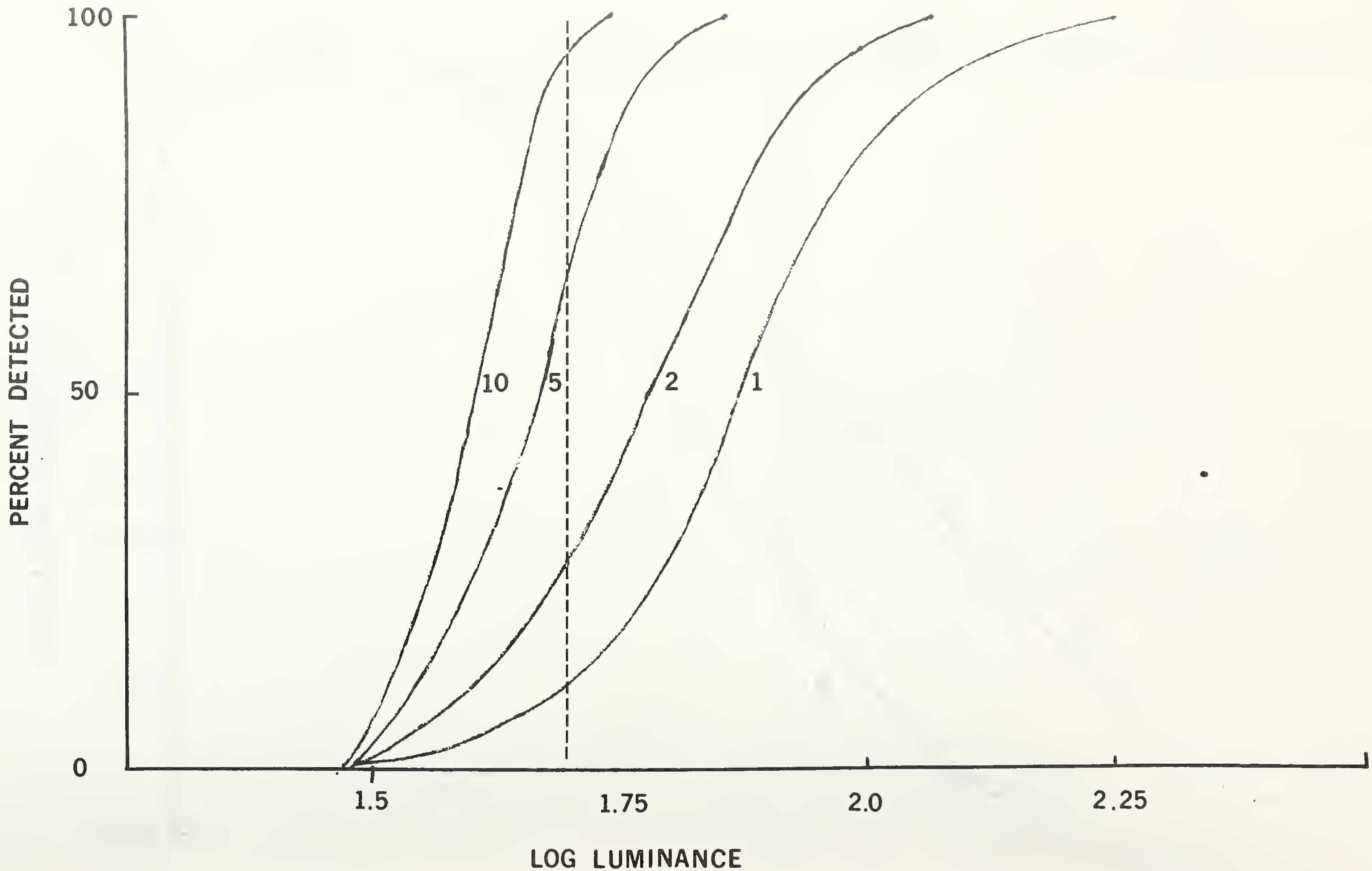


FIG. 4 - Target Detection Probability by Groups Composed of 1, 2, 5 and 10 observers. Adapted from Ref 2.

## LUMINANCES OF COMMON VISUAL STIMULI

| LUMINANCE $CD/M^2$ | |
|---|---|
| $10^6$ | TUNGSTEN FILAMENT |
| $10^5$ | UPPER LIMIT OF VISUAL TOLERANCE |
| $10^4$ | WHITE PAPER IN SUNLIGHT |
| $10^3$ | |
| $10^2$ | |
| | COMFORTABLE READING |
| $10^1$ | |
| 1 | |
| $10^{-1}$ | |
| | WHITE PAPER IN MOONLIGHT |
| $10^{-2}$ | |
| $10^{-3}$ | |
| | WHITE PAPER IN STARLIGHT |
| $10^{-4}$ | |
| $10^{-5}$ | |
| | ABSOLUTE THRESHOLD |
| $10^{-6}$ | |

FIG. 5 - Luminance levels of typical visual stimuli. Adapted from Ref 3.

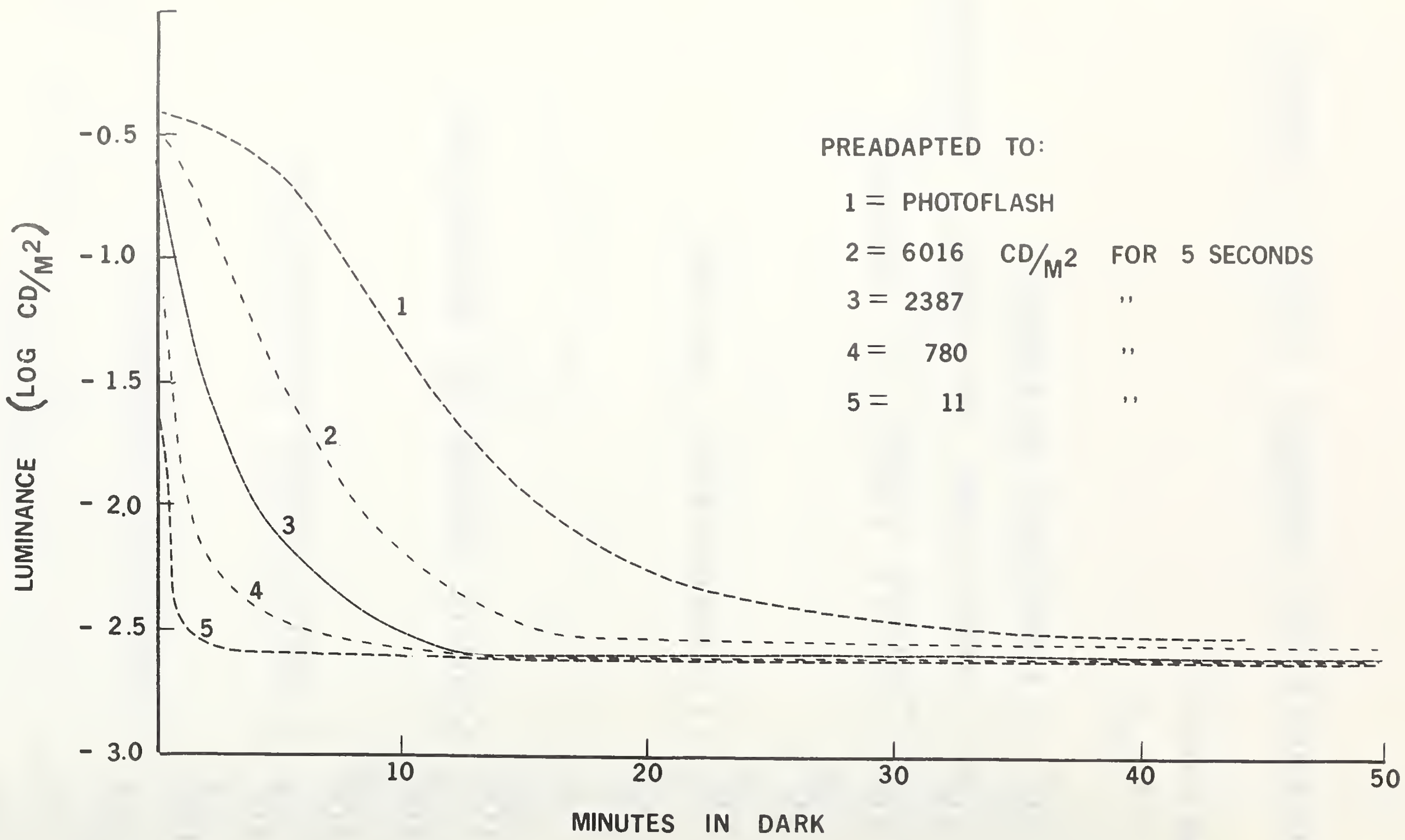


FIG. 6 - Dark adaptation threshold following short exposures to high luminances. Adapted from Ref 4.

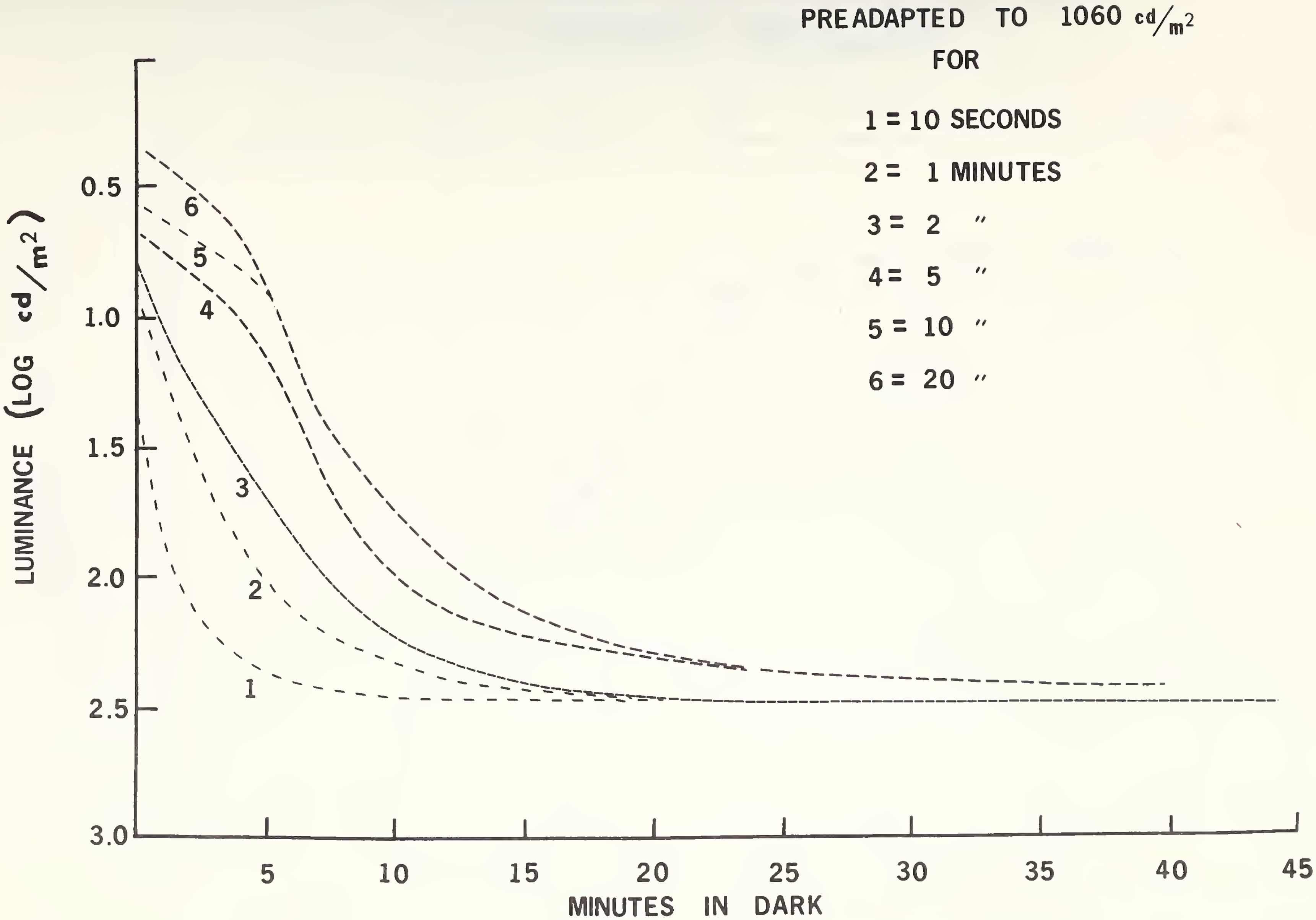


FIG. 7 - Dark adaptation thresholds following exposures to a luminance of 1060 $cd/m^2$ of different durations. Adapted from Ref 4.

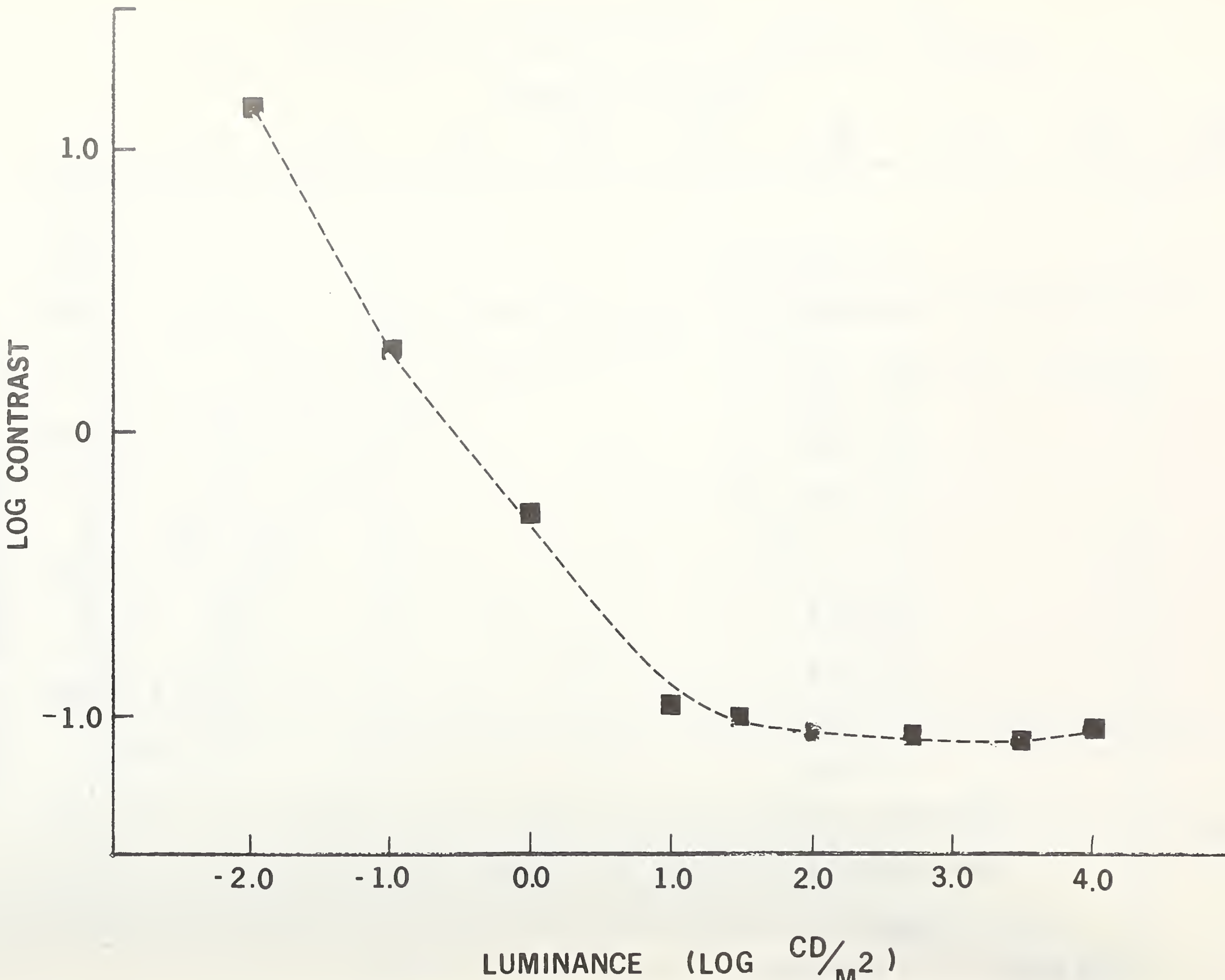


FIG. 8 - Luminance contrast threshold as a function of background luminance. Adapted from Ref 2.

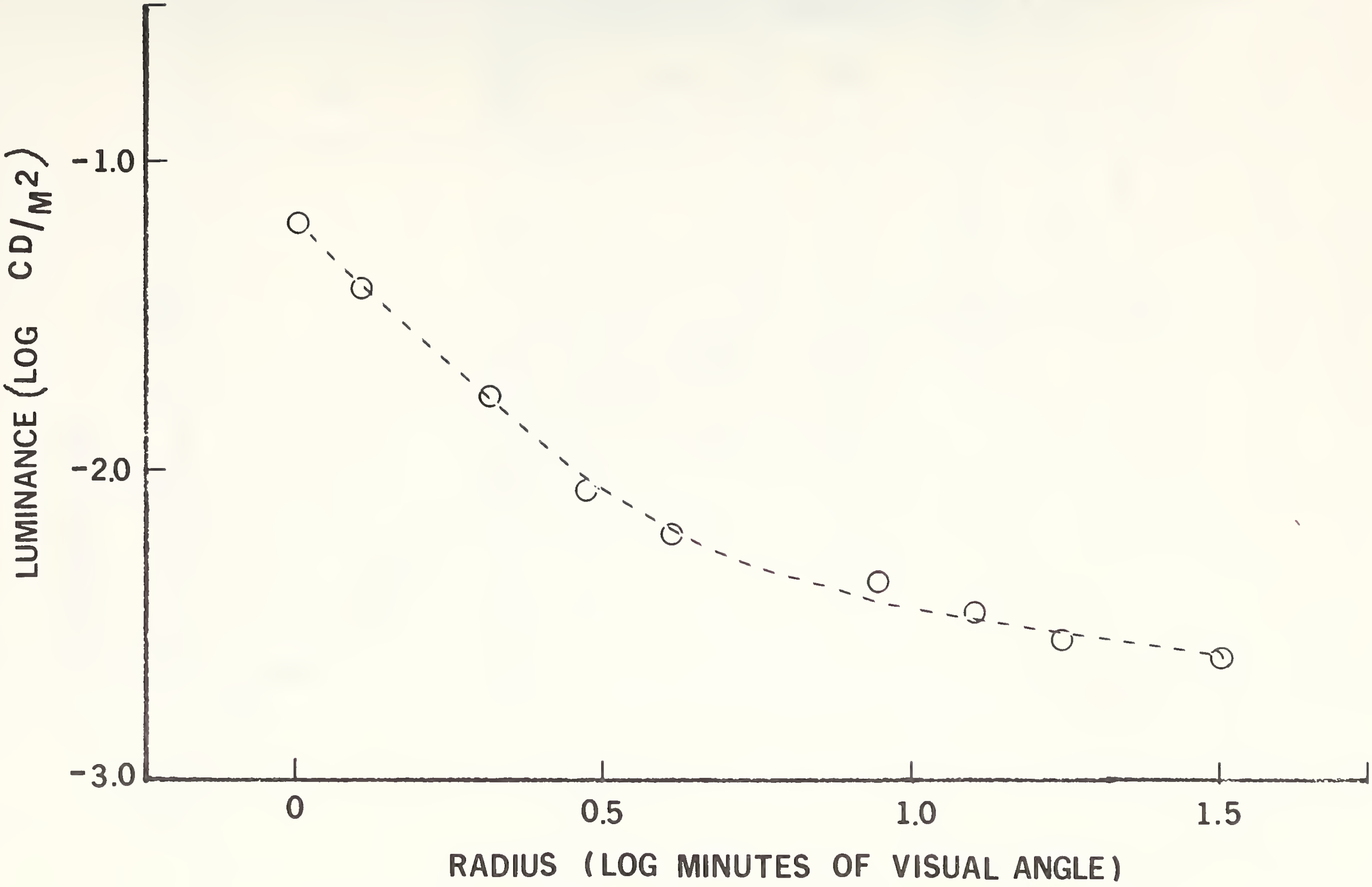


FIG. 9 - Threshold luminance as a function of radius of a circular target. Adapted from Ref 5.

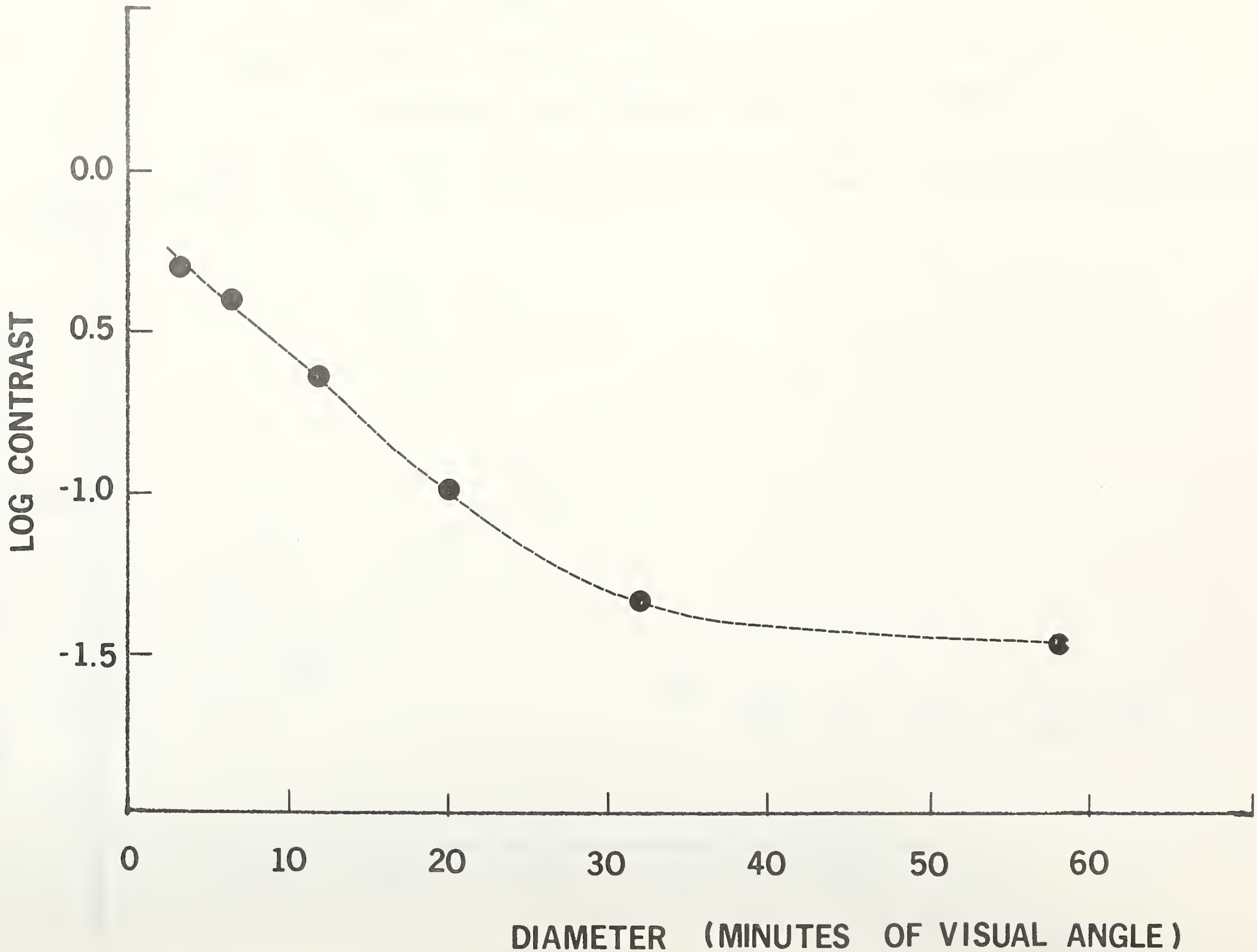


FIG. 10- Contrast threshold as a function of the diameter of the test field. Adapted from Ref 6.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

When we look at the capacity of the human visual system we see that it has many capacities depending on the circumstances under which it is used. The sensory data show that man can adjust to a wide variety of operating conditions. But, unless we have detailed information of the conditions for which these processes are to be optimized and quantitative descriptions of the tasks to be performed, the advantages to be obtained by visual science applications cannot be optimally utilized. Physical correlates of the response should be quantified, followed by a systematic scaling of the physical correlates for application to nondestructive testing. The Modulation Transfer Function widely used in optical imaging assessments would be an evaluation technique applicable to hardware, processing and image description.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Nondestructive testing; modulation transfer function; vision; visual acuity; visual capacities

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