Optimization of the Gray Scale for Photoscanners: Concise Communication

Wei Chang* and Monte Blau

State University of New York at Buffalo, Buffalo, New York

A gray scale providing easy visual interpretation of black-and-white photoscan transparencies was determined empirically from psychophysical studies conducted on 50 observers. This optimum gray scale provides equal visualization for equal count-rate changes over the entire film range.

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Although techniques of organ imaging have been markedly refined, little work has been done in optimizing the final step of the picture-making process, i.e., the transformation of count-rate information into shades of gray on film—the gray scale. The sensitivity of the human eye to small variations in shades of gray is intrinsically nonlinear with respect to the mathematically defined parameter, optical density (OD), over the commonly used optical-density range (0.2–2.0 OD). Based on tests of 15 subjects, Laughlin et al. (*1*) reported a marked decrease in perception sensitivity with increasing background optical density—i.e., it takes a larger difference in optical density to be just perceivable on a dark background than on a light background.

No investigation of the gray scale as used in nuclear medicine has been done since Laughlin's early work. There are many studies in the psychological literature concerning the perception of brightness (*2–5*), but none of these is directly applicable to photoscan interpretation. Since the problem of gray-scale perception is just one form of brightness perception (transmission film serves only as a neutral filter on a bright background), we have used psychophysical techniques to investigate the problem of perception of the gray scale as used in nuclear medicine.

METHODS

The experiment was designed to measure the ability to perceive differences in gray shades at different optical densities under standard viewing-box conditions.

Thirty-one film strips, 6- × 50-mm, each with uniform optical density, were selected from exposed film with measured densities* from film-fog level to full black. The selection of these film strips was based on a preliminary test to assure that enough possible choices could be made at any density level by an observer in the psychophysical test. The bright background of the viewing box was blocked by a cardboard mask. The series selection was carried out on the mask, which had seven rectangular holes, 5- × 40-mm, arranged parallel to each other, with 3-mm separations (Fig. 1).

Each of the 50 subjects was asked to pick out those five gray strips that he felt represented equal density steps between the two extremes, 0.15 and 3.05 O.D., which were already placed in the top and bottom slots of the series of seven holes. The subject could make as many comparisons and modifications as he wanted until a satisfactory series

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* Present address: Department of Nuclear Medicine, Loyola University Medical Center, 2160 S. First Avenue, Maywood, Illinois.

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For reprints contact: Wei Chang, Dept. of Nuclear Medicine, Loyola University Medical Ctr., 2160 S. First Ave., Maywood, Illinois.

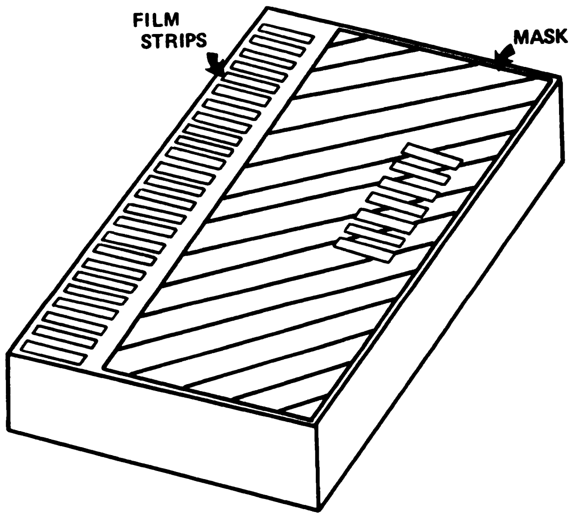

FIG. 1. The psychophysical experiment. The 31 strips in the gray series on the left are movable, so that the observer can place them over the holes at the right, only five of which are open. The two holes at the ends contain optical densities of 0.15 and 3.05, and the subject's task is to find five movable strips that, when placed over the five open holes, form a series of seven increasing shades, each differing from its neighbors by the same perceived contrast.

was determined. The result was a series of seven strips that divided the gray scale range into six steps of equally perceptible density difference. In order that the selection should not be influenced by the way the sampling was arranged, the subject was asked to make selections from a random series of strips instead of from a lined-up ascending or descending series. The test usually took 20-30 min.

RESULTS

Each of these six steps represents one unit of the scale of the "differential perceptibility" of optical density. Plots of differential perceptibility against optical density were made for each individual. There was little variation in the general pattern among observers. The average of these 50 empirical curves is shown in Fig. 2. At low optical densities, small changes are readily perceived but at high optical densities the curve is approaching a plateau. This results from the nonlinearity of the response of the human visual system and the mathematical definition of OD (OD = $\log \frac{I_0}{I}$, where I_0 = incident light and I = transmitted light).

DISCUSSION

The relationship between count rate and film density in a photoscanner is the result of a series of linear and nonlinear electronic data manipulations in combination with the nonlinear response of the film to light. The net result is the "gray scale" that relates count rate to film density.

It is from this gray-scale display that the clinical observer attempts to reconstruct in his mind the distribution of radioactivity in the patient. His contribution to the series of nonlinearities in the system is a "differential perception" of shades of gray. We have measured this function empirically in a series of observers. There was surprisingly little variation between individuals.

Correct evaluation of a photoscan requires that the gray scale of the scanner be matched to the nonlinearities of human perception. The electronic data circuits should compensate for the nonlinearities of the film response and human perception. When this is done properly, a set of linear changes in count rate will produce a set of film densities that are perceived as equally spaced shades of gray (according to the data in Fig. 2). Only then can the observer be certain that his visual judgment reflects the relative distribution of radionuclide in the patient rather than some distorted presentation of the data.

Unfortunately, many, if not most, photoscanners introduce such distortions because of their poorly conceived gray scales. Figure 3A shows a typical gray scale generated by using a series of pulses with frequency decreasing linearly in 10% steps. At the low end of the scale the 10% changes in count rate are readily perceived but at the high end it is difficult to see any change in density even with 20% or 30% changes in count rate. Clearly, the gray scale of this scanner is not well matched to the human eye. Figure 3B shows the gray scale of a scanner that has been modified to match closely the empirical differential perception curve shown in Fig. 2.

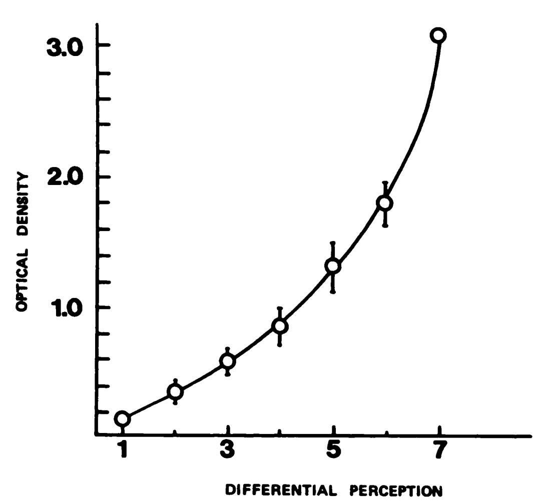

FIG. 2. Empirical curve of differential perception plotted against optical density. Average of 50 subjects. Vertical bars indicate range of experimental values.

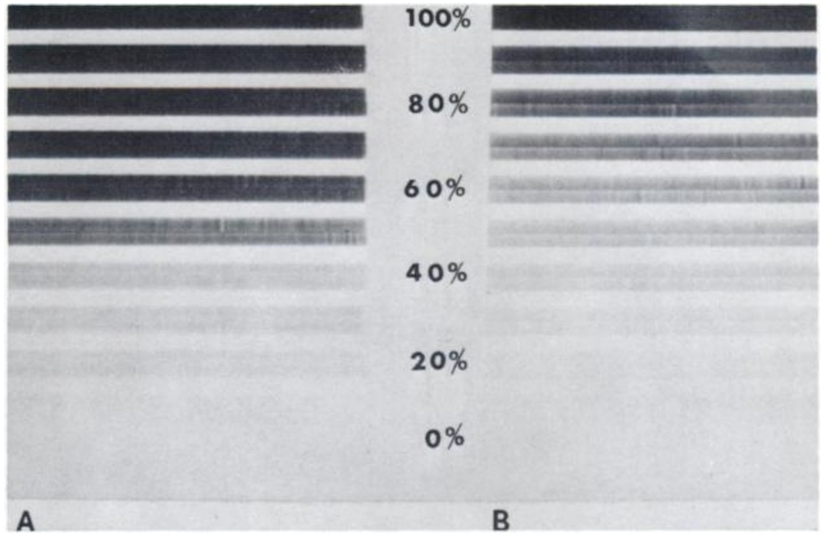

FIG. 3. (A) Typical gray scale generated by using pulses of decreasing frequency in 10% steps. (B) Modified gray scale to match the empirical differential-perception curve. Fine structure in each of the strips results from scanning motion that is not perfectly smooth.

The steps are now spread more evenly, making those at the light end more difficult to tell apart but permitting differentiation of count-rate changes at the dark end of the scale. By use of the data in Fig. 2 it has been possible to extend the gray scale up to an OD of 3 as well as achieve uniform density differences. (Reproduction of these gray scales by printing fails to reveal the true relationship, since they are designed to be viewed as transparencies.)

It will sometimes be desirable to manipulate the gray scale to provide contrast enhancement or accentuation of one end of the scale or the other. When this is done, it should be in a carefully controlled and well-understood fashion, so that the observer can take the manipulation into account in his interpretation. A useful technique is to generate gray scales with the same manipulation and have these on hand for reference during scan reading. A numerically calibrated scale such as is used with CT scans is also helpful.

The appropriate electronic modification of commercial photoscanners is fairly difficult to achieve in practice. The relationship between count rate and film density is achieved differently by each machine, usually by circuits that are not easy to modify. What we wish to stress is that human perception measurements must be taken into account when imaging devices are designed.

The differential perception curve in Fig. 2 is applicable only to photoscanners producing transparency films. With computer data processing, scintillation images obtained from an Anger camera can also be reproduced with a preselected gray scale. A similar experiment would have to be carried out for other forms of data presentation, including Polaroid film and cathode-ray-tube readouts.

FOOTNOTE

* Photovolt Densitometer Model 525

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