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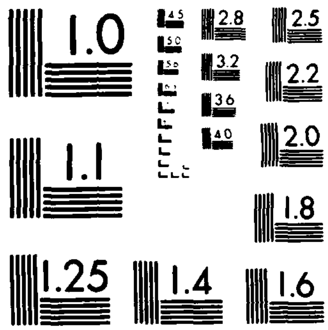

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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 1031

INDIVIDUAL DIFFERENCES IN CHROMATIC BRIGHTNESS MATCHING

by

S. M. Luria and D. F. Neri

Naval Medical Research and Development Command
Research Work Unit M0100.001-1019

Released by:

W. C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

3 October 1984

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SUMMARY PAGE

PROBLEM

To measure the individual differences in brightness matches of lights of different cololrs at bright and dim intensity levels.

FINDINGS

Individual differences are very small; the standard deviation of the matches made by 52 observers never exceeded 0.1 log unit.

APPLICATION

Problems encountered in maintaining brightness matches of different indicator lights on submarine control panels do not ariese as a result of individual differences in the color perception of different operators, but must be sought elsewhere.

ADMINISTRATIVE INFORMATION

This research was undertaken under Naval Medical Research and Development Command Work Unit M0100.001-1019 - "Improvement of sonar performance through modification of sonar displays." This report was submitted for review on 28 Aug 1984, and approved for publication on 3 Oct 1984. It has been designated as Naval Submarine Medical Research Laboratory Report No. 1031.

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ABSTRACT

Individual differences in brightness matches between lights of different colors were determined for color-normal observers at both photopic and mesopic light levels using the method of flicker photometry. The standard deviations of the settings made by 52 observers at photopic levels did not exceed 0.1 log unit. Variability was greatest at the extremes of the spectrum. Variability was not appreciably increased at mesopic levels.

INTRODUCTION

The increasing use of color-coded control panels on submarines has raised the question of whether or not brightness matches for different colors made by one individual will be acceptable to others. An operator using such a panel prefers the various indicator colors to be equally bright, and will therefore adjust the brightness of those lights which he considers brighter or dimmer than the others. The question has been raised, however, as to whether or not the brightness matches made by one individual are acceptable to others. Are individual differences in heterochromatic brightness matching so great that it is difficult to get agreement between individuals?

There is surprisingly little information on the variability of brightness matches of different colors from one individual to another. Pickford (1), in his book dealing with individual differences in color vision, discussed the relative abilities of men and women to discriminate brightness differences, and he took up the question of whether or not color-defectives are better able to judge brightness differences than color-normals. But, he did not make clear what the variability of these different groups is.

A great deal of research has been done on brightness matching of lights of different colors for the purpose of specifying the luminosity curve, which specifies the relative sensitivity of the visual system to different wavelengths. Much effort has been devoted to making such determinations under a variety of conditions, such as different levels of light-adaptation, different chromatic adaptation, different sized stimuli, different retinal locations, etc. Usually in these studies a large number of measurements are made on a small number of subjects. Indeed, it is not unheard of for experiments of this type to be carried out on only one subject (2-7). The information about variability that such studies gives us is mainly how precisely a given observer can make the required judgment, how the values change under the different conditions, or, at most, how similar the global luminosity curves of different observers are.

We now know quite precisely what the mean luminosity curve is under a variety of conditions, but it is still not clear how great the individual differences are between luminosity curves. There are several reasons. First, often only the range set of curves is given; yet the range is the poorest of the measures of variability. There is no way of knowing if a wide range is the result of only one deviant subject, while all the others were tightly grouped. For example, Bedford and Wyszecki (8) noted that the large variability in part of their data was due to "the abnormally low red sensitivity of one observer." Second, the luminosity curves are often plotted as relative luminosity, which makes the variability in absolute terms uncertain. Finally, it is commonplace to "pin" the various curves at around 560 or 570 nm; that is, the curves are plotted so that they all go through one point at a given wavelength,

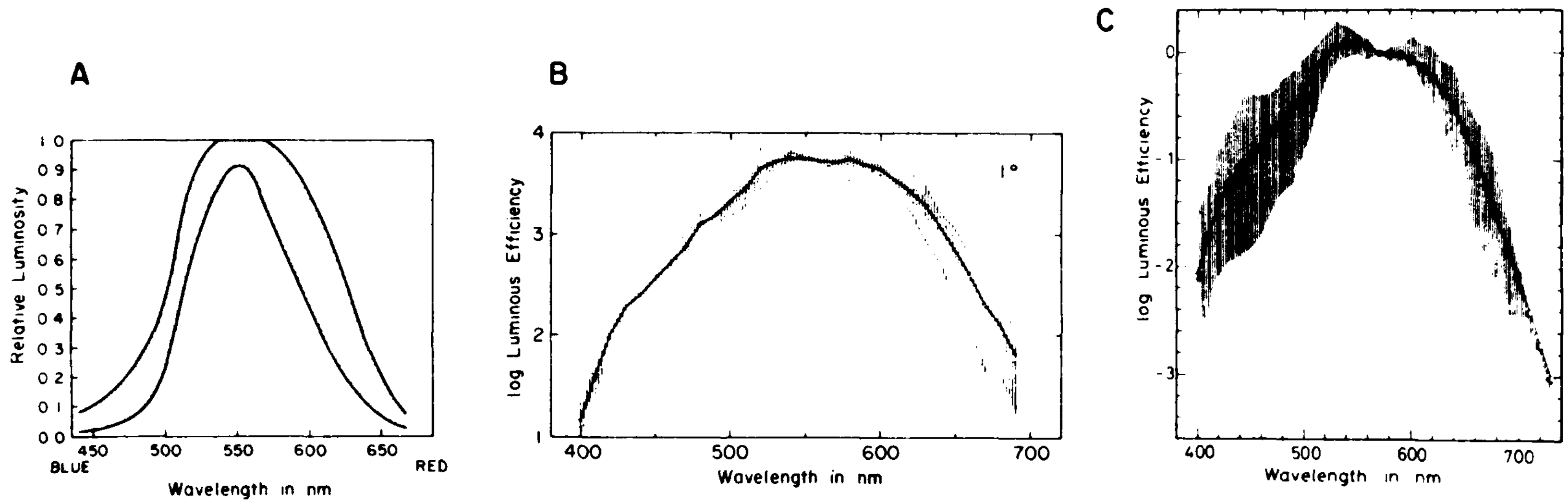

Fig. 1. Range of individual variation in luminosity curves as reported by Judd (A), Bedford and Wyszecki (B), and Ikeda et al (C).

thus eliminating all variability at that point and distorting the actual variability elsewhere.

Generally, reports giving information about the individual differences of luminosity curves appear to indicate that they are substantial. Bedford and Wyszecki (8), in their study of the luminosity curve, comment that there are "considerable differences...several times larger than those obtained on repeated curves by any observer." They have presented several figures comparing the luminosity curves obtained by several investigators (Fig. 1). They show a range of variability between observers of as much as a log unit at some wavelengths. Judd's (9) figure giving the range of variability for 37 normal observers has often been reprinted (Fig. 1). It shows a range of relative luminosity measurements of almost half a log unit at 600 nm. Ikeda et al.(10) have published a similar figure compiling the data from a number of studies (Fig. 1); these data, which have been pinned, show a range of individual differences exceeding a log unit in the short wavelengths.

Some investigators have presented the actual curves of all their subjects. Hsia and Graham (11) presented the scotopic (or night-time) luminosity curves of five subjects and seven photopic (daytime) curves (12); in both cases the range of individual differences is about a log unit in the short wavelengths. A larger collection of individual data has been published by Ishak (13). He has presented the luminosity curves of 15 Egyptian trichromats. Although he notes that their curves differ somewhat from the luminosity curves of Europeans, his data permit us to calculate their actual variability. The dispersion is about 0.2 log unit at 450 nm, .12 log unit at 500 nm, and .01 log unit at 550 nm, after which it gradually increases until it reaches .13 log unit at 700 nm.

The impression that there are great individual differences in luminosity curves has led to the presumption that there is also considerable individual variability in heterochromatic brightness matching. Some years ago Cornsweet (14) wrote, "...when two patches are different in wavelength, equal brightness settings are very unreliable..." More recently, Boynton (15) has written, "Consider... a 555-nm green light on one side of a bi-partite field with a 465-nm blue field immediately adjacent to it... We ask an observer to adjust the intensity of the blue field until it looks 'equally bright' as the green one. This turns out to be rather difficult." Kinney and Culhane (16) probably speak for most authorities when they sum up the situation by saying, "It is well demonstrated that people with normal color vision (color-normals) differ widely in sensitivity to light of different wavelengths... These individual differences imply that two [observers]...will often not find one set of brightness settings satisfactory for both people at the same time."

The largest group of subjects in a heterochromatic brightness matching experiment was reported by Dwyer and Stanton (17). They tested a total of 50 subjects, but they represented several groups. Twenty were

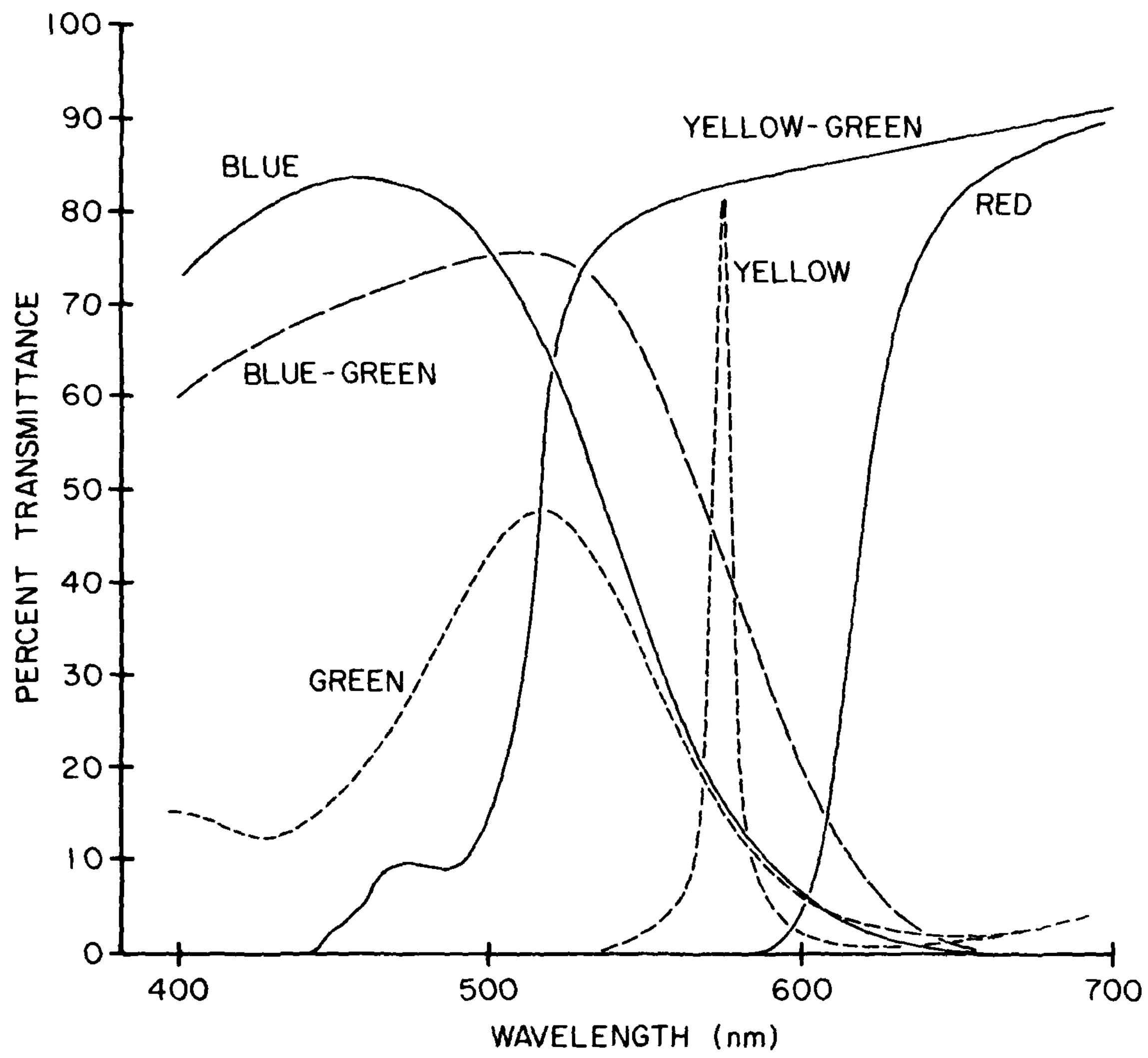

Fig. 2. Spectral transmittance curves of experimental stimuli.

white, and thirty were black. Both the whites and black were further subdivided, the whites according to eye-color, and the blacks according to skin-pigmentation. Dwyer and Stanton were investigating whether or not there were racial differences in color vision. All the subjects matched five wavelengths, from 399 to 667 nm, to a white standard using the method of adjustment and the method of limits (mistakenly identified as the method of constant stimuli). They found that the variability of the brightness matches increased significantly with pigmentation; the lowest variability was found for the blue-eyed whites, and it increased progressively to a high for the most heavily pigmented blacks. There was also a significant difference between the two psychophysical methods. If we may disregard the significant differences and average the variability for all five pigmentation groups and the two psychophysical methods, then the mean variability ranges from a high of .071 log unit for 399 nm to a low of .066 log unit for 578 nm. Although their aim was not to assess the range of individual differences, these data suggest that it is not as large as has been assumed.

The aim of this investigation was to assess the individual differences in brightness matching of different colors by color-normal observers. Since Dwyer and Stanton have presented data using the method of heterochromatic brightness matching, we have used the method of flicker photometry. It seems clear that matching by flicker is mediated by different systems than is standard heterochromatic matching (18). There is little doubt that matching is much easier with this method and might well produce even less variability than do the other psychophysical methods.

There is one other question. Is the individual variability different at different luminance levels? Aboard submarines, operations are conducted at various ambient light-levels ranging from 20 fc to total darkness. It might be expected that the variability of such matches might be much greater at mesopic (intermediate) light levels owing to the complexity of the change-over from the photopic to mesopic luminosity curves (19,20). The purpose of this study, then, is to determine the variability in brightness matching of different colors between observers at both photopic and mesopic light levels.

METHOD

Stimuli

Six colored filters with dominant wavelengths of 490, 500, 525, 575, 580, and 620 nm were chosen. Observers identified them as clearly being blue, blue-green, green, yellow-green, yellow, and red. Their spectral transmittance curves are shown in Fig. 2. All were broad-band filters except the yellow.

Apparatus

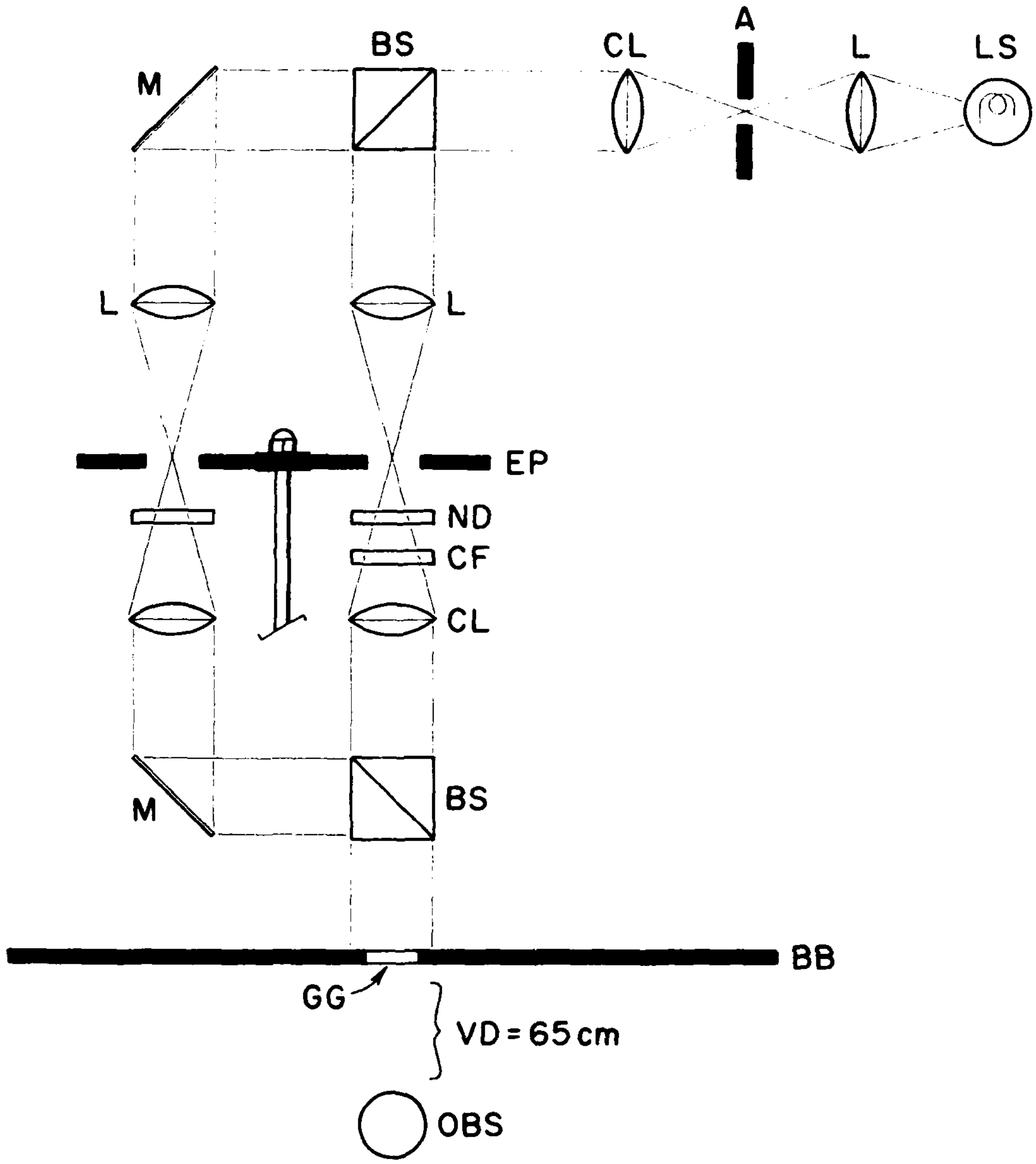

Fig. 3. Diagram of the optical system for flicker photometry. LS, light source; L, lens; A, aperture; CL, collimating lens; BS, beam-splitter; M, mirror; EP, episcotister; ND, neutral density filters; CF, chromatic filtering; GG, ground glass; BB, white bainbridge board.

The different colors were matched by flicker photometry using the optical system diagrammed in Fig. 3. The standard to which all the colors were matched was provided by the light of the projection bulb dimmed by neutral density filters to a luminance level of either 26 fc for the photopic viewing condition or to 0.2 fc for the mesopic condition, as measured at the ground glass aperture with a Spectra Pritchard Photometer, Model 1970 PR. The luminance of the white surround was set at either 19 or 0.19 fc for the two conditions. At the viewing distance of 65 cm, the stimulus subtended a visual angle of 2 deg. The flicker rate was about 15 fps as measured with a General Radio Strobotac. Ikeda and Shimozono (21) have concluded that a flicker rate of at least 4-6 fps is sufficient.

Procedure

The colors were matched to the standard using a staircase method, with the luminance of the colored stimuli being changed in 0.1 log unit steps. The subjects were told that their task was to judge the changes in the prominence of a flickering light. As they looked at the flickering light, a neutral density filter was inserted in the optical path. Each time this was done-- the insertion of the filter was distinctly audible-- they judged whether the flicker had become more or less prominent. They were shown that this did not depend on the apparent brightness of the stimulus; the salience of the flicker could either increase or decrease while the brightness was either increasing or decreasing. We made sure that they understood that they were not judging the changes in brightness.

As the luminance of the colored stimulus was progressively increased (or decreased), starting with some random intensity level which was appreciably brighter or dimmer than that of the standard, the subject typically reported that the flicker was becoming less pronounced. At some point he reported that it had become more pronounced. The density of the neutral filter was recorded, after which the density of the filters was changed in the opposite direction, and so on, thus allowing an assessment of the width of the zone of subjective equality; Boynton and Kaiser (22) have pointed out the necessity of this determination in flicker experiments. The mid-point of this range was taken as the point of subjective equality.

The six colors were presented in a different random order to each subject. For the mesopic conditions, the subjects were adapted to the intensity of the surround for 5 minutes before beginning their observations.

Subjects

Fifty-two color normals, either staff members of the laboratory or their dependents observed in the photopic condition. Fifteen were women. Twenty of them, including six women, returned to observe in the mesopic condition.

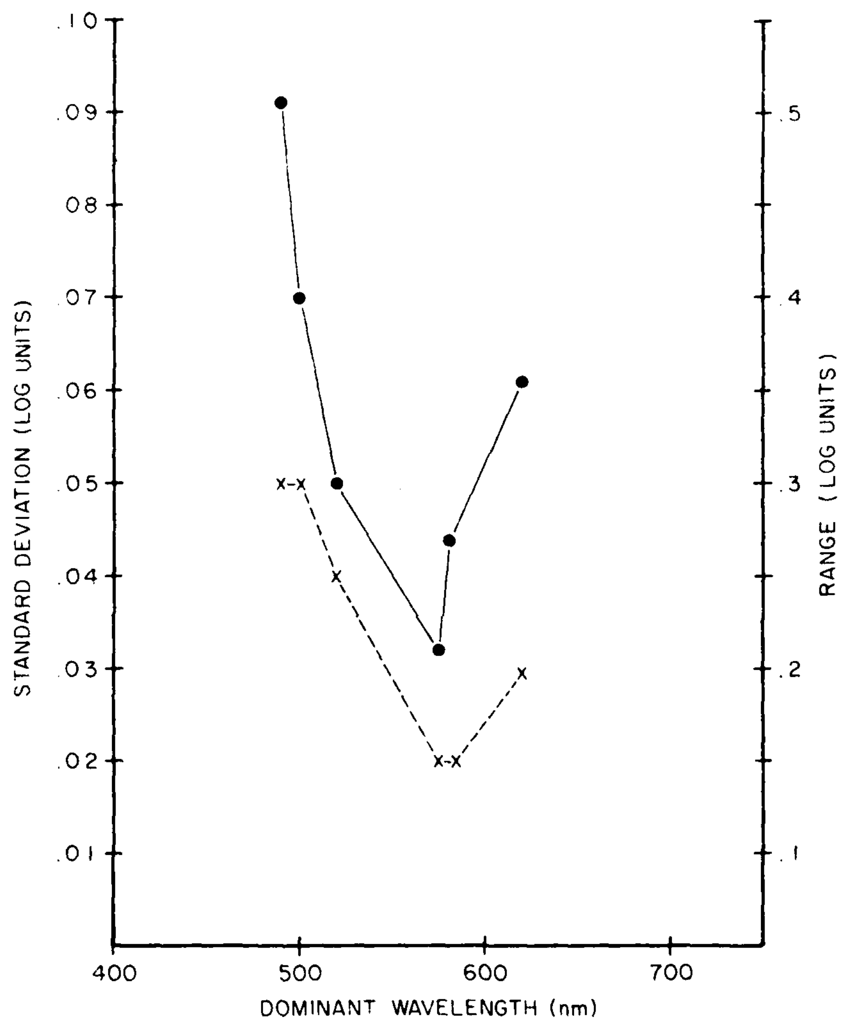

Fig. 4. Range (X) and standard deviations (•) of the filter settings used to match each wavelength to the standard by the 52 subjects.

RESULTS

Both the ranges and the standard deviations of the brightness matches of each color to the standard at the photopic light level are shown in Fig. 4. The largest range of 0.3 log unit is comparable to that previously reported, but the standard deviations for the matches are almost an order of magnitude lower. None is as great as 0.1 log unit; they range from a high of .09 at 490 nm to a low of .032 log unit at 575 nm, the entire curve describing a U-shaped function.

The mean variability of the matches made by the 20 observers at the mesopic level ranged from .055 to .087 log unit. There was clearly no particular increase in the variability, and the total sample of 52 observers was therefore not tested.

Finally, there were no significant differences between the mean settings of the men and women. Interestingly, however, the neutral density filters selected by the men at the short wavelengths were less dense than those used by the women, but there was a progressive decline with wavelength in the densities chosen by men relative to those chosen by women, so that at the two longest wavelengths the women chose denser filters. Moreover, the men were significantly more variable than the women with the 490 nm ($p > .05$) and 620 nm ($p > .01$) filters.

DISCUSSION

These results indicate that the individual differences in the brightness matches of the different colors were quite small. The standard deviations of the matches were all less than 0.1 log unit. These values are quite similar to those found by Dwyer and Stanton (17) using other psychophysical methods. The U-shape of the curve also conforms to the results of Dwyer and Stanton, to the general shape of the composite curves drawn up by Bedford and Wyszecki (8), and Ikeda et al (10), and to results of individual observers such as those published by Sperling and Hsia (23), who published sensitivity data for four subjects throughout the spectrum which allows us to calculate standard deviations. For their four subjects, it is .40 log unit at 550 nm, for example, .17 at 500 nm, and only .08 at 550 nm, after which the variability increases again.

Since the individual variability is apparently quite small regardless of the psychophysical method used, why has it generally been assumed to be large? One answer is clearly because the luminosity curves of different observers are often quite different in their general level of sensitivity. However, it does not necessarily follow from this that individual differences in brightness matching of different wavelengths will also be large. It is possible that, although the general level of sensitivity is different, the relative sensitivity to the various wavelengths is much more constant. A brightness match between two wavelengths made by one observer would then quite likely be acceptable to other observers. Morover, the composite curves which have been presented have sometimes overestimated the individual variability, because luminosity curves obtained under quite different conditions have been grouped together.

A second reason may be that heterochromatic brightness matching is not a task which subjects like to do. On the contrary, it evokes a great deal of complaint and protestations that they cannot do it. Nevertheless, it is a truism in psychophysics that observers can often do things that they themselves are convinced they cannot do. But the impression of undependable and variable results appears to remain.

It was expected that individual differences would be greatly increased under mesopic conditions. The mesopic luminosity curve is actually a family of curves which changes somewhat unpredictably from one individual to another as the intensity changes through the mesopic range. There was, however, no marked increase in variability, and testing was discontinued after 20 subjects. It is clear that whatever differences there are in the luminosity curves, they are not enough to appreciably increase the differences in brightness matching of selected wavelengths.

In short, the magnitude of individual differences in matching the brightness of different colors, by whatever method, appears to be relatively small. The difficulty of making such matches and the reluctance of most observers to come to a decision further ensures that matches made by one color-normal observer will generally be acceptable to most other color-normals.

These results indicate that individual differences in the perception of the brightness of different colors are not the cause of the problems encountered in "grooming" the highly color-coded control-panels now being made for submarines-- that is, in satisfactorily equating the brightness of the various colored indicator lights. The reason for this problem lies elsewhere. It is possible that the marked differences in the brightness of different indicator lights are caused by variations in the electrical power reaching the lights at different times.

ACKNOWLEDGMENT

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