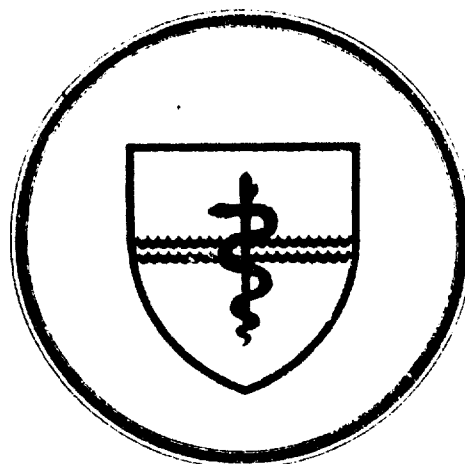
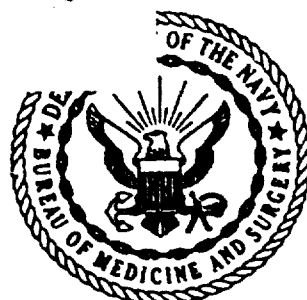


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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.



REPORT NUMBER 998

COLD WEATHER COGGLES:

V. Acceptable Limits of Optical Distortion

by

S. M. Luria

and

Roberto Rodriguez, HM2

Naval Medical Research and Development Command
Research Work Unit M0095.001-1040

Released by:

William C. Milroy, CAPT, MC, USN

Commanding Officer

Naval Submarine Medical Research Laboratory

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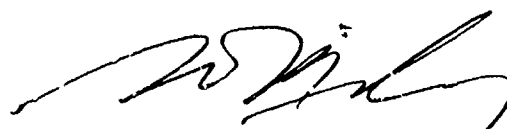
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S. M. Luria, Ph.D.
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SUMMARY PAGE

PROBLEM

To determine the maximum amount of optical distortion which does not significantly degrade the performance of tasks typically performed by Marines in the field.

FINDINGS

Contrast sensitivity, acuity through binoculars, depth perception, and riflery were compared with subjects wearing a series of goggles with different amounts of optical distortion. The magnitude of distortion was quantified by projecting a Snellen chart through each of the goggles and determining the Snellen line which observers could read. Using this criterion, the maximum permissible distortion (that is, which does not significantly impair the above tasks) is that which degrades acuity from 20/20 to the 20/30 line.

APPLICATION

These findings are relevant to the specification of the characteristics of protective sunglasses for use in the Arctic and other bright environments.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command work unit M0095.001-1040 - "Protective devices for the eye in cold weather." It was submitted for review on 9 Mar 1983, approved for publication on 11 Apr 1983, and designated as NAVSUBMEDRESCHLAB Report No. 998.

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ABSTRACT

Contrast sensitivity, acuity through binoculars, depth perception, and riflery were measured as subjects looked through goggles with various degrees of optical distortion. The amount of distortion necessary to produce a statistically significant degradation of performance was determined for each task in order to specify the maximum allowable optical distortion in goggles. The degree of distortion was quantified by projecting a Snellen chart through the goggles and determining the Snellen line which could then be read. By this criterion, the maximum permissible distortion is that which degrades acuity from 20/20 to the 20/30 line.

INTRODUCTION

A survey of the optical properties of commercially available cold-weather goggles has shown that they exhibit a range of characteristics.¹ The most obvious is the variety of spectral transmittances. When put through the series of tests which are used to evaluate Air Force visors for optical quality, however, they also exhibited a range of various optical distortions. These tests are very stringent--as might be expected for use by aircraft personnel--but it is likely that ground forces can function effectively with goggles of lower optical quality.

A subsequent study, therefore, measured the effects of wearing goggles of various levels of optical quality on the performance of several tasks which must be carried out by troops in the field.² These included riflery, looking through field-glasses, depth perception, and the like. The optical distortions found in the commercially available goggles did not degrade performance on any of the tests for most subjects; only the expert riflemen suffered a statistically significant but small degradation in their shooting. The question arises, therefore, how much optical distortion can be tolerated? At what point does the performance of practical tasks begin to be significantly affected?

In this study, four goggles were fabricated which exhibited a range of optical distortions which exceeded those usually found in commercial goggles. Their effects on performance were measured in an effort to specify the permissible limits of optical distortion for

cold weather goggles for men in the field.

THE GOGGLES

Performance in various practical tasks was, with one minor exception, not affected by the previous range of distortions. However, it seemed that the limits of acceptable distortion had been reached and any further increase in distortion would produce significant degradations of performance. Such magnitudes of distortion would exceed, however, that which is typically found in commercial goggles. It was necessary, therefore, to find a way to produce large magnitudes of distortion. Our solution was to use the heavy (0.3 mm thick), molded plastic containers in which new safety goggles are encased for sale. To increase the amounts of distortion, several layers of this plastic were put together. The total transmittances for the different sets were then equated with neutral density filters.

In the previous evaluation, optical quality was measured using tests of prismatic deviation, spherical distortion, and viewing distortion.² The magnitude of distortion of the layers of plastic, however, was too great to be measured with the sensitive tests used for the Air Force visors. Indeed, Wulfeck et al³ have commented that "while distortion is a recognized evil in transparencies, it is difficult to evaluate with objective tests." We assessed the magnitude of distortion by holding the plastic in front of a Snellen Chart projector and noting the mean Snellen line which could then be read by three subjects. Table I gives the mean Snellen values for the five pairs of goggles used in this study: clear safety goggles (which the previous tests had shown to exhibit

Table I. Mean Snellen acuity line legible when the Snellen Chart was projected through the different goggles.

Goggle	Snellen acuity
Clear safety goggle	20/20
One layer plastic	20/25
Two layers plastic	20/35
Four layers plastic	20/50
Six layers plastic	20/80

very little optical distortion) and one to six layers of plastic, all with equated transmittances. These values range from a mean of 20/20 for the least distorting goggles, the commercial safety goggles, to a low of 20/80 for goggles made of six layers of plastic. The goggles are hereafter identified by these mean Snellen values.

It is important to note that the observers did not wear these goggles while reading the Snellen chart; the goggles were placed in front of the projector which projected the Snellen chart. The observers were wearing no goggles when they read the chart.

CONTRAST SENSITIVITY

The first task to be tested was the ability to see grating targets of various spatial frequencies. This test is a more informative test of the visual state than simple resolution acuity. It gives an indication of the ability to see large objects as well as small ones. It is now well known that there may be a loss in the ability to perceive

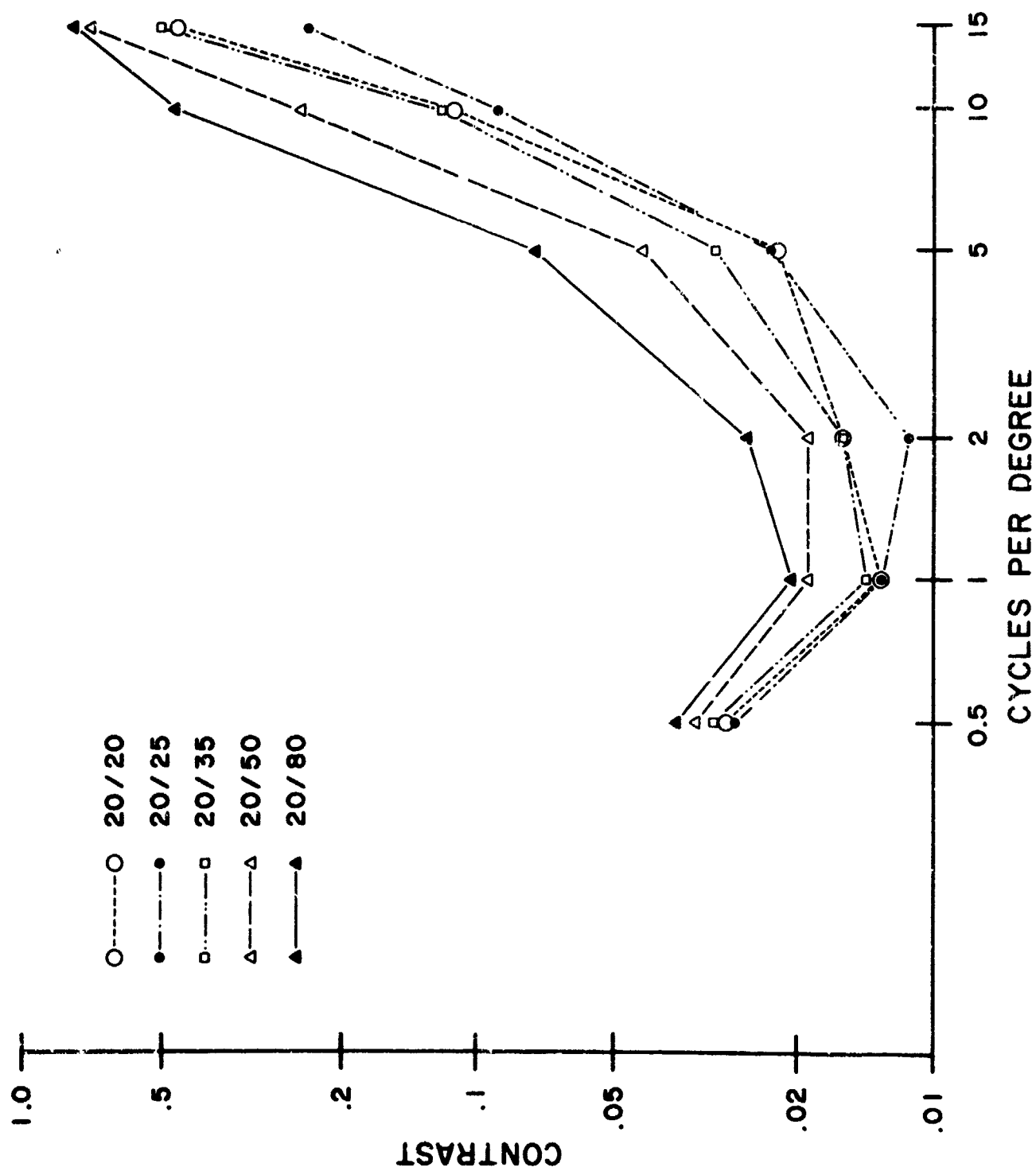
one and not the other.⁴

Method

Vertical square-wave gratings were generated on a Hewlett-Packard cathode ray tube (CRT) with a P31 phosphor. At the viewing distance of 300 cm, the screen subtended $5^{\circ} \times 3.8^{\circ}$ visual angle. Six spatial frequencies were chosen to sample the contrast sensitivity function. The mean luminance was about 0.6 mL and the surround was illuminated to about .03 mL. Thresholds were measured with the ascending method of limits. With the subject wearing a given pair of goggles, a spatial frequency was selected and presented below threshold. Its contrast was increased in preselected steps until the subject would report its size. A new frequency was selected at random and the process repeated. This continued until each of the six frequencies had been presented three times. The procedure was repeated with each pair of goggles. Six members of the laboratory staff were tested. Each wore the goggles in a different random order.

Results

The mean thresholds at each spatial frequency through each pair of goggles are shown in Fig. 1. The most sensitive function in this family of curves is virtually identical with that obtained with different subjects wearing the least distorting goggles in the previous study. At the lowest spatial frequency the thresholds with the various goggles are only slightly different from each other, but as the spatial frequency increases, the effects of the distortion become more pronounced. This is shown in Fig. 2 which gives the ratios of the



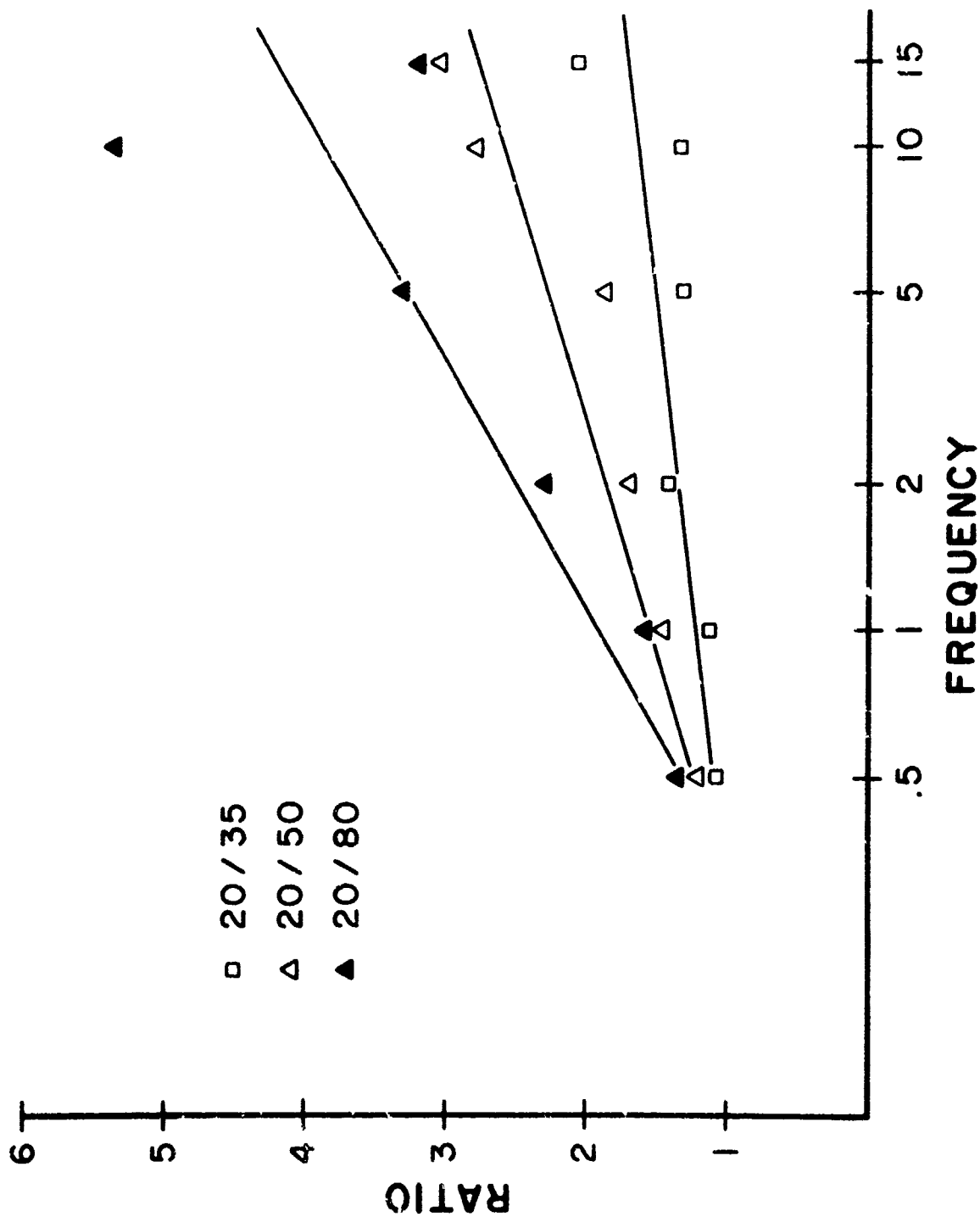


Fig. 2. Ratio of mean contrast sensitivity for a given spatial frequency obtained through each of the three most distorting goggles to the best mean contrast sensitivity at that frequency.

contrast threshold at each frequency through different goggles to the best contrast sensitivity obtained at that frequency. The greater effect of the optical distortion on the higher spatial frequencies was confirmed by an analysis of variance. This showed that the goggles were not significantly different at 0.5 and 1 cpd, and that the differences between the goggles fell just short of significance at 2 cpd. At 5 cpd, however, the differences reached statistical significance ($p < .05$) and they were highly significantly different ($p < .01$) at 10 and 15 cpd.

A Tukey test showed that at 5 cpd, only the most distorting goggle was significantly worse than the best goggles. At 10 and 15 cpd, the two most distorting goggles were significantly worse.

ACUITY THROUGH BINOCULARS

Although a test of resolution acuity might be considered less informative physiologically than contrast sensitivity, the ability to see through binoculars involves the additional parameters of the ability to hold the field glasses up to the eyes and to actually see a target in the field. It is of interest to compare such results with the laboratory test.

Method

Acuity was measured using a series of high contrast black-and-white grid targets positioned 3700 ft from the subjects, according to a U. S. Geodetic Survey map. Thresholds were measured using the method of constant stimuli. The subjects reported whether the gratings were horizontal or vertical.

A solid gray target, matched in mean luminance to the gratings was used to check that the subjects were not guessing. The targets were 15 inches square and subtended 8 minutes visual angle when seen through the 7-power binoculars. Observations were made for short periods at the same time each day, so that the position of the sun on the target was constant. The binoculars were held by the subjects without the help of a tripod or mount.

Ten laboratory staff members participated, wearing the goggles over their spectacle corrections if necessary. They wore the goggles in a counterbalanced order.

Results

Figure 3 shows the mean width in seconds of arc of the stripe of the threshold target seen through each of the goggles. As the magnitude of distortion of the goggle increases, the size of the target threshold increases. An analysis of variance shows these differences to be highly significant ($p < .01$). A comparison of the means using the Wilcoxon matched-pairs signed-ranks test shows that the means for the first two goggles (20/25, 20/35) are not significantly different from the mean obtained with the clear goggles, but the mean obtained with the third goggle (20/50) is significantly different ($p < .01$) from the mean with the clear goggles as was, of course, the most distorting goggle.

DEPTH PERCEPTION

There is previous evidence that distortion affects depth perception. Schachter and Chapanis⁵ tested the effects of five degrees of distortion in glass on performance on the Howard-

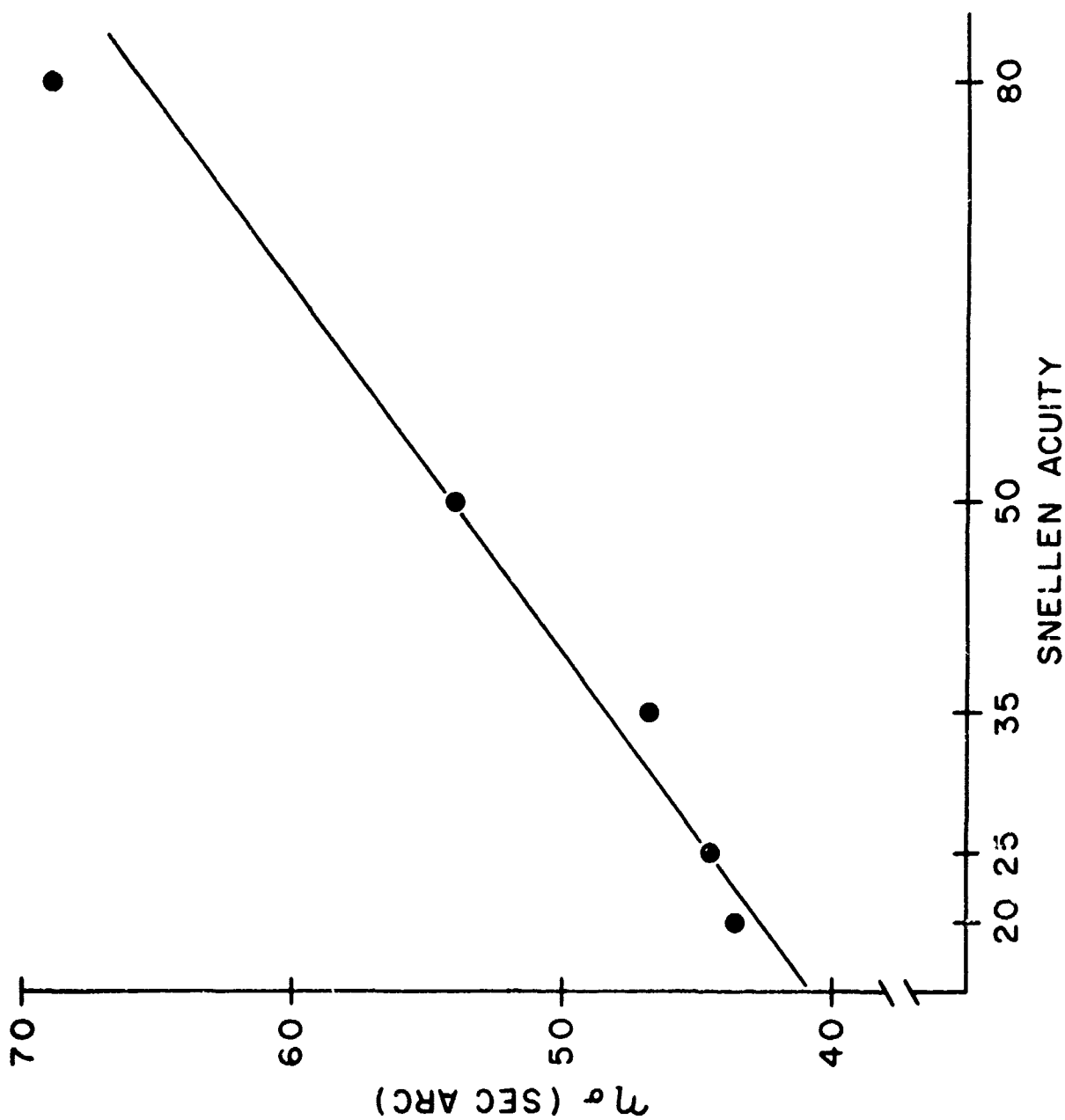


Fig. 3. Mean stripe width in seconds of arc of threshold target perceptible through each of the goggles.

Dolman test. They also tested the effects of presenting the glass at different angles to the line of sight. Schachter and Chapanis found that the most marked effects resulted from looking through the glass at large angles from the perpendicular; although all the distorting glasses degraded depth perception to some extent, the different degrees of distortion did not produce systematic changes for the lesser viewing angles. The problem of viewing angle is relatively unimportant with goggles, of course, since the goggles are fixed on the head. We are more concerned with differences in perception as a function of the degree of distortion in the glass. Schachter and Chapanis quantified their distortion by making a double exposure photograph of a grid, with and without the glass in the light path, and it is difficult to equate their magnitudes of distortion with ours.

Method

Stereoacuity was measured with a three-rod Howard Dolman apparatus. The two outer rods were fixed in position at a distance of 6 m from the subjects. The middle rod was movable. These black rods subtended $.06^\circ$ visual angle and were separated by $.72^\circ$. They were visible through a $1.3 \times 3.5^\circ$ window in the dark gray faceplate and were seen against a white background illuminated to about 25 fL.

Thresholds were measured with the method of constant stimuli. The movable rod was set at various positions, the window of the apparatus was opened, and the subject judged whether the rod was closer or

farther than the fixed rods. A frequency-of-seeing curve was drawn on cumulative probability paper, and the variability of the settings was read from the plot.

Ten laboratory staff members participated. They wore the five pairs of goggles in a counterbalanced order.

Results

Figure 4 shows the mean variability of the thresholds obtained through the various goggles. There was a progressive degradation of performance through the distorting goggles as the amount of distortion increased. (A plot of the localization errors, not shown, is quite similar). The differences between the goggles are highly significant, according to an analysis of variance. The differences between the means for the different goggles were tested with the Wilcoxon matched-pairs signed-rank test. The Wilcoxon test indicated that adjacent goggles were not significantly different, but goggles not adjacent were different. That is, the 20/25 goggle was not significantly worse than the safety goggles or significantly better than the 20/35 goggle. However, the 20/35 goggle was significantly worse than the safety goggles. Similarly, the 20/50 goggle and the 20/80 goggle were not different, but the 20/80 goggle was worse than the 20/35, and the 20/50 was worse than the 20/25.

RIFLERY

In the previous investigation² it was found that the performance of a group of riflemen of average skill was too variable to produce statistically significant differences with

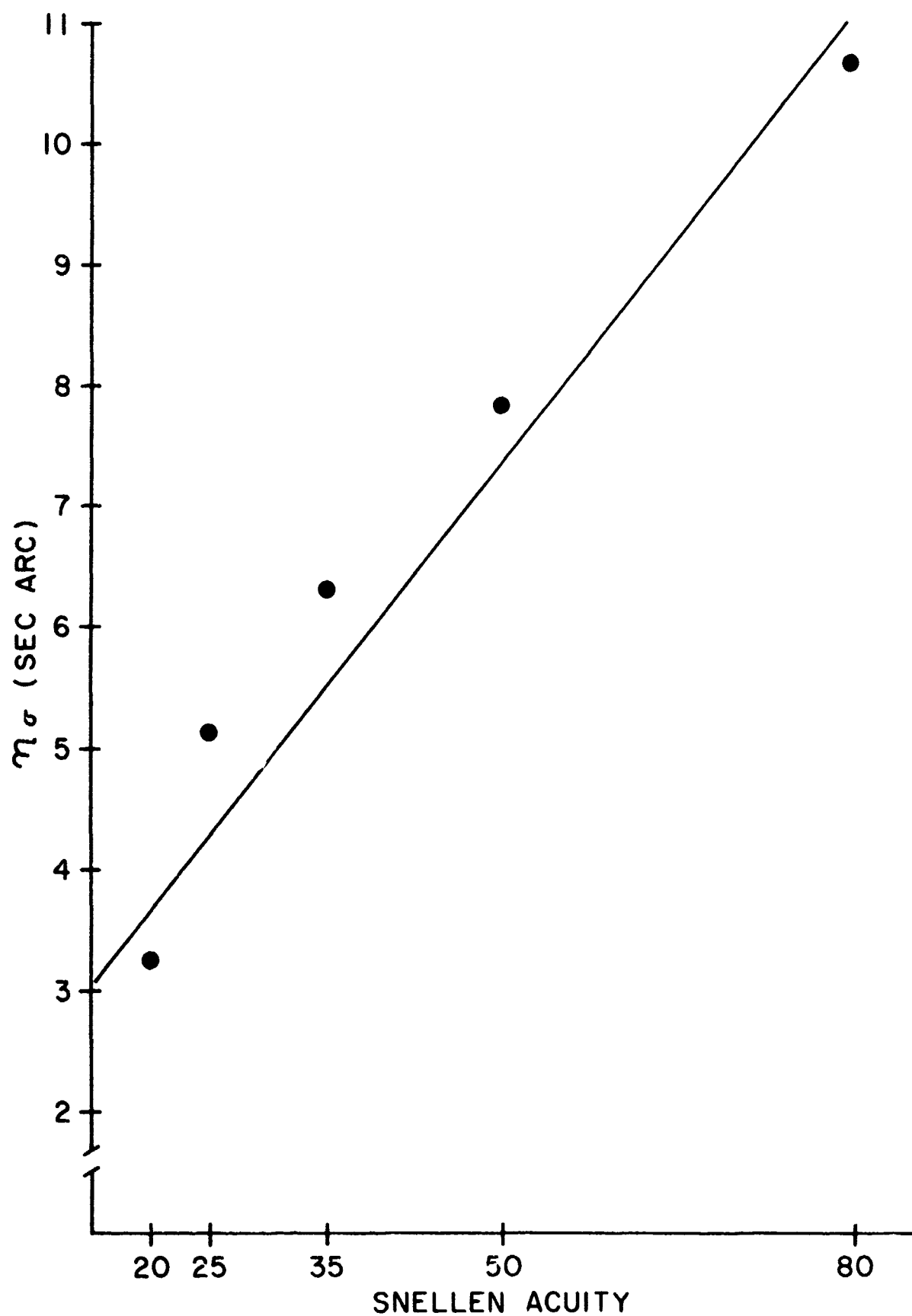


Fig. 4. Mean variability of the equidistant localization setting (in seconds of arc) with the Howard-Dolman depth perception apparatus through each of the goggles.

these small samples. With men of superior skill, on the other hand, performance was so reliable that degradations of performance were much more evident. For that reason, volunteers were solicited from the superior marksmen in the company.

Only the most distorting goggles produced a significant degradation of performance in the previous study. There were two pairs of goggles in this study which were appreciably more distorting than that.

Method

This study was again carried out on a military rifle range immediately after the "shooting for record" which is required periodically for every Marine. Each subject thus had an extended practice period immediately before the experiment. Each subject shot 10 rounds from the prone position at targets 300 yards away while wearing each of the goggles. The men did not learn their scores until the end of the experiment. Half the subjects wore goggles in order of increasing distortion and the other half wore them in order of decreasing distortion.

Ten men from the Naval Submarine Base Marine barracks participated.

Results

Figure 5 shows the mean score for the 10 men with each pair of goggles. A perfect score is 50. It is clear that these men constituted a superior group of riflemen. Figure 5 shows that there was, in general, a progressive decrease in accuracy with increasing distortion.

According to the Wilcoxon Signed-Ranks Test, the most distorting goggles produced results that were significantly worse ($p < .05$) than the results with the least distorting goggles.

DISCUSSION

Goggles with four degrees of optical distortion were produced using low grade plastic material. Subjects then attempted to carry out four tasks while wearing the various goggles. A pair of clear, safety goggles was used as the standard of comparison; previous investigations had shown that these goggles exhibited very little optical distortion and did not affect performance.

The magnitude of distortion was quantified by projecting a Snellen chart through the goggles and determining the Snellen line which could be read. According to this procedure, the most distorting goggles used in the previous study allowed a mean acuity of about 20/40. In the present study, the maximum distortion was greater and allowed a mean acuity of only 20/80.

In the previous study, the maximum distortion produced only one significant degradation of performance--in the score of a superior group of riflemen. Although there were degradations in the other tasks, they did not reach statistical significance. It was concluded, however, that that level of distortion was on the threshold of significant impairments of performance.

In this study it was quite clear that increasing the distortions produced a systematically increasing loss of performance, and was enough to

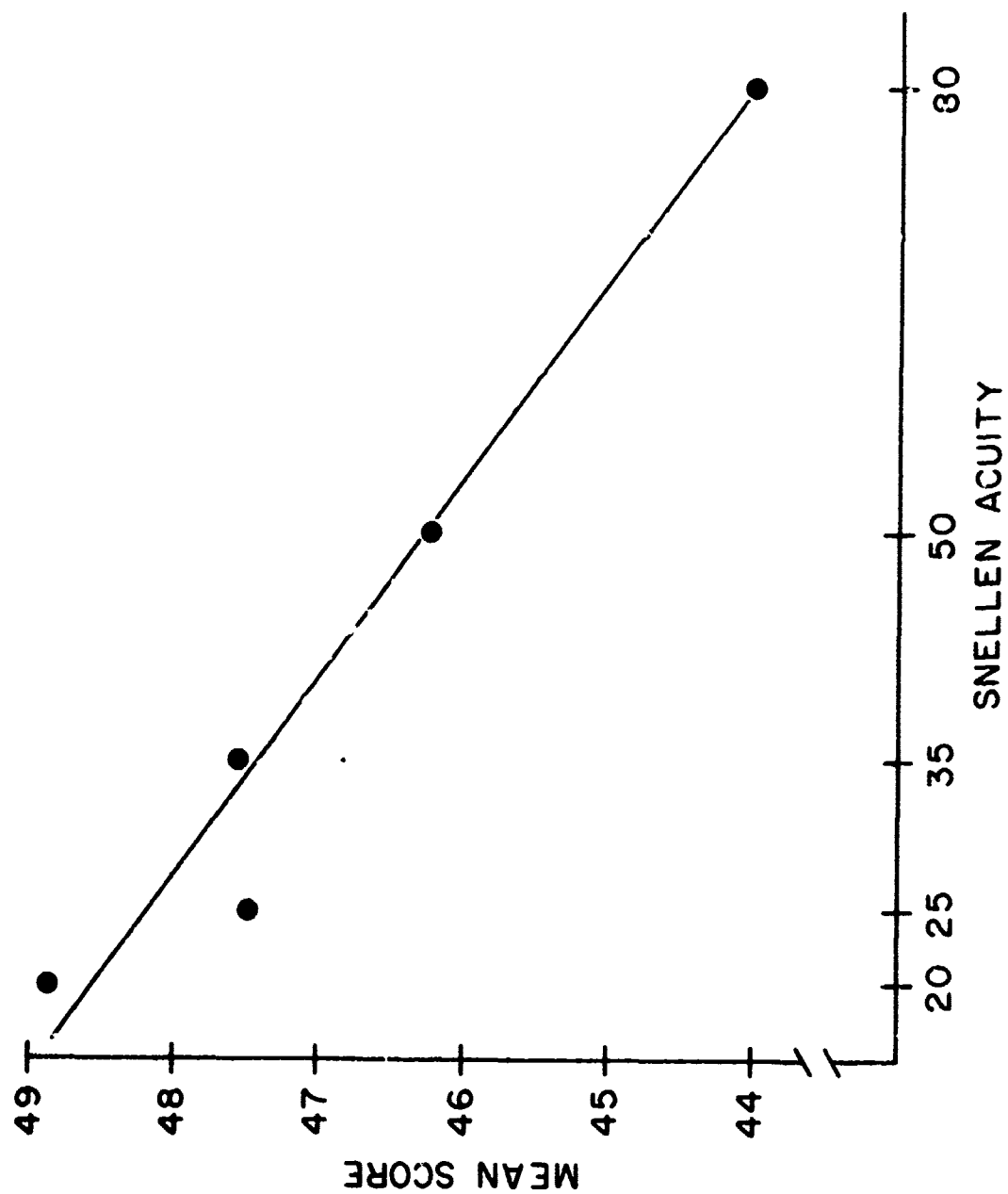


Fig. 5. Mean rifle scores obtained while wearing each of the goggles. A perfect score is 50.

produce a significant degradation in every task; three of the four tasks were significantly impaired with less distortion. With the present subjects, one task, depth perception, was impaired by the goggles which allowed an acuity of 20/35. It appears, then, that the maximum allowable distortion, as presently defined, should be that which allows a Snellen acuity of 20/30.

This magnitude of distortion is, in fact, considerable. Of the dozen goggles tested previously, only three exhibited poor optical quality of this magnitude. Most were much better. In specifying this degree of distortion as the maximum allowable, the basis is simply the degree of impairment in a series of tasks, each of which has been carried out over a very short period of time. This, indeed, represents a maximum degree of permissible distortion, for the present results do not take into consideration the possibility that much smaller amounts of distortion might, over a longer period of time, produce significant impairments in performance. A level of distortion which allows an individual to successfully perform a visual task may, however, produce an impairment over an extended period of time. There is little evidence that feelings of fatigue are typically accompanied by impairments of performance,⁶⁻¹¹ but there has apparently been no study of whether or not optical distortions lead to complaints of visual fatigue.

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