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IN
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THE DESIGN AND USE OF OPTICAL INSTRUMENTS IN CONNECTION WITH UNDERSEA WARFARE

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INTRODUCTION

Optical instruments of importance in submarine and anti-submarine warfare consist, in the main, of various forms of telescope. Each instrument is designed for one or more specific functions, but they all have in common the general purpose of aiding the eye in the detection and examination of relatively distant objects. In the discussion which follows, a survey will be made of factors known to be of importance in visual detection and examination. Consideration will then be given to the limitations of optical instruments, particularly in comparison with the naked eye and with radar and sonar. Special problems of optical instrument design will then be considered, and the human factor will be considered in relation to these design problems.

THE ADEQUACY OF TELESCOPIC INSTRUMENTS FOR VARIOUS PURPOSES

Increasing the Visual Range

One of the chief functions of telescopic instruments is to extend the effective operating range of the eye by aiding the operator (a) in the detection of targets too distant to be detected by the unaided eye and (b) in the examination or recognition of targets too distant to be seen clearly by the unaided eye.

Let us consider first the ideal situation of viewing a black and white target in the absence of any absorption or scattering of light by the atmosphere. In this situation the effect of range is simply to reduce the size of the image of the target on the retina of the eye without altering the contrast, luminance, sharpness of contour, or temporal stability of that image. A perfect telescope is then able to compensate perfectly for any increase in range by a corresponding increase in the magnification of the instrument, or, in the ideal case $R = Mr$, where R is the effective telescope range; M, the magnification; and r, the range of unaided vision.

It is only in the idealized situation pictured above that a telescope can be made to extend indefinitely the range at which a target may be observed. The remainder of this paper may be regarded as a discussion of how the value of telescopic magnification is limited by other factors, such as atmospheric absorption and distortion, the inherent defects of telescopic instruments, and the inevitable human factors of visual defects and errors of operation. It is obviously true, for example, that atmospheric conditions set a limit beyond which visual observation cannot be effective, no matter how good the telescopic instrument may be. Daylight visual range is defined by international agreement among meteorologists as the greatest distance at which a large dark object on the horizon is just recognizable against a sky background. Another unit, known as meteorological range, is also in common use. This is the horizontal distance at which a large black target appears to be 2% less bright than the sky background. This value is usually slightly greater than the daylight visual range, for the reason that a contrast of slightly greater than 2% is commonly required for the recognition of a large dark object on the horizon.

Whereas telescopic aids are of minimum value in observing large objects at distances approaching the meteorological limit, they are maximally effective in observing small objects which are relatively close at hand. The value of telescopic magnification is chiefly in making small objects appear sufficiently large, and this can best be accomplished under good viewing conditions, and at distances much smaller than that represented by the meteorological range. Quantitative data to support this conclusion are given in the section on atmospheric limitations appearing below.

To summarize the situation in respect to extending the visual range by means of telescopic instruments: At one extreme, the meteorological range or daylight visual range, either unit being defined in terms of very large objects, cannot be extended. At the other extreme, the effective range at which a very small object may be viewed can be extended almost indefinitely up to the limiting meteorological range by increasing the magnification of the instrument, particularly when atmospheric limitations are small. Between these two extremes, the detection and examination of distant objects is facilitated by telescopic instruments.

Probably the most elaborate set of field tests of visual range in which optical instruments were employed is described in a report entitled "Field Tests of Optical Instruments" (35). This is a report of some experiments under the active direction of W. S. Verplanck at the U. S. Naval Submarine Base at New London, Connecticut. For the purposes of this section, we shall confine our attention to the instrumental aspects only of this study. The instruments used in these experiments included hand-held and mounted binoculars having magnifications of from 6 to 25 power and objective diameters from 33 to 120 mm. Monocular instruments covering approximately the same range were also used, hand-held and mounted, and some obsrvations were made with the naked eye. Fairly naturalistic targets were employed in this study, and the instruments were used on board ship by naval personnel. The targets ranged from a few inches to many feet in width and were located on the shore of a small island. They had various degrees of contrast such as might be encountered under actual field conditions.

The results of the above experiments have been analyzed for three different criteria of visual performance: (1) when the observer could just see the target for an instant, only to have it fade out of sight; (2) when he could dimly see the target continuously; and (3) when he could recognize the target by its size, shape and position. The standard 7x50 binoculars were taken as the standard of reference for the performance of the other instruments.

The principal conclusions of this study are as follows: (1) A binocular instrument is superior to a monocular for night use by a factor of at least 10 percent in terms of visual range. There is scarcely any difference between binocular and monocular instruments for daytime use. (2) Magnification up to at least 10-power for a hand-held instrument and 20-power for a mounted one increases the effective range at night. Magnification above 6-power does not improve daytime performance for hand-held binoculars but does increase the value of mounted instruments up to at least 20-power. (3) The best all-round hand-held binocular is the 10x50x7°. The best all-round mounted binocular is the 20x120x3°. (4) The range of an instrument is extended by approximately 10 percent by the provision of suitable mounts or rests for hand-held instruments. (5) Differences among instruments are more striking in the sighting and identification of targets than in problems of search. (6) Further research is required relative to individual differences among observers under various conditions of visibility in the use of optical instruments of this character.

A British report (53) summarizes some experiments in which binoculars have been employed for observing targets of high contrast at low brightnesses in a perfectly clear atmosphere. It is shown that even under optimal conditions binoculars do not extend the visual range by as great a factor as the magnification.

Increasing the Probability of Detection

At any given range an object which is near the threshold of detectability may or may not be detected in the process of visual search. Over a certain low range of contrast values of the target and its background, there is a definite region of uncertainty. Sometimes the target is seen, sometimes not. In general, the probability of target detection is related to the luminance contrast, $\frac{|L_O - L_B|}{L_B}$ where L_B is the background luminance and L_O, the luminance of the object or target. This probability function, which is sigmoid in shape, depends on an appreciation of a minimal difference between the numbers of nerve impulses delivered to the brain per unit area and time from retinal elements stimulated by target and background.

Hecht and his co-workers (15) have concluded that the sigmoid function is based in part upon statistical considerations within the stimulus itself. For a source of constant intensity and a series of flashes of equal duration, there is a Poisson distribution of number of quanta per flash of light. At intensity values near the visual threshold, the number of quanta per flash or unit of time therefore varies considerably because of variations in the stimulus itself. Thus, if a certain minimum number of quanta is necessary for seeing a flash, the probability that it will be seen varies by reason of factors in addition to physiological variations. It is concluded that the absolute threshold under the most favorable conditions of seeing is characterized by the absorption of one quantum of light by each of 5 to 14 retinal rods. The sigmoid curve is, therefore, the result of factors in the stimulus or in the observing individual, or both.

The military significance of increasing the probability of detection lies, of course, in the ability to conduct a successful search for any targets which may appear to be brighter or less bright than their backgrounds. Field studies, to which reference is made later in this report, have been conducted to indicate the degree of such success under given conditions of illuminations, size of target, magnification, and other particular factors which may be present.

With this statement of problems of threshold detectability, let us turn to what is known about the improvement of target detection by the use of optical instruments.

Detection at Nighttime Levels of Illumination

Hartline and McDonald (36) have discussed the probability of detection or "frequency of seeing" at low illuminations. The laboratory studies of frequency of seeing which are most pertinent to the present discussion are those conducted during World War II at Dartmouth College, Brown Univeristy, and the University of Pennsylvania (46). In all of these studies, tests on indoor observing ranges were made with binoculars of various magnifications and exit pupils. An evaluation was made of psychological and physiological factors which govern the visual assistance furnished by binoculars.

At Dartmouth college, the binoculars employed were 6x30, 7x35, 8x40 and 10x50. The brightness levels were .000037, .00037, .0037 and .037 footlamberts. The targets were circular black dots against the dimly-lit background. The observer was allowed six seconds to look, at the end of which time he signaled the position in which he saw the target. Six different sizes of target were used at each of four positions for each set of brightness and magnification conditions. Curves of frequency of seeing were determined as functions of the log of the diameter of the target. The results of the Dartmouth experiments may be summarized as follows: the use of binoculars greatly increases the range of detection of small targets at night. This advantage is greater the higher the magnification up to 10× and shows no sign of falling off at this value. This conclusion holds true over the entire range of brightnesses.

The Brown University experiments (34, 46) were concerned with similar problems but were considerably more extensive. In one series of experiments, exit-pupil diameters of 2, 4, 6, 8 and 10 mm. were employed with 5-power binoculars. It was found that better performance resulted as the exit-pupil diameters were increased up to 6 mm. Beyond this point, however, increasing diameter did not result in any improvement. This is somewhat surprising in view of the fact that the average diameter of the natural pupil at that low level of brightness is approximately 7 mm. Another series of experiments compared the efficiency of seeing with various magnifications in binoculars with 50-mm. objectives. In these experiments, it was found that performance improved as the magnification was increased up to 10×, then fell off for magnifications greater than that. This result is to be expected on the basis of the fact that the exit-pupil diameter was inversely proportional to the magnification in this series. Other experiments, with 70-mm. objectives, revealed that the visual range was improved by only about 5 percent over that of the 50-mm. instruments.

How bout art. pupil advantage

The results of the Brown University experiments in general conform to the principle that the threshold of visibility is determined by the contrast between target and background. For small targets at low levels of illumination, retinal summation is complete and it is found that this threshold is proportional to the product of the area of the target by the target contrast. Since the area varies inversely with the square of the range, the threshold range should vary in proportion to the square root of the contrast. An exception to this general rule was found for contrasts below 50 percent where the observed ranges were unaccountably lower that the predicted ones.

In addition to these main findings of the Brown University experiments, certain other relevant factors were investigated. Alidade mounting of the binoculars resulted in an average gain of about eight percent in terms of visual range. Angular motions simulating those to be encountered on shipboard produced no definite loss for periods of oscillation greater than 12 seconds; and for shorter periods, the range was decreased by a relatively small amount. The relative advantage of using two eyes over single-eye observations ranged between 19 and 26 percent for the naked eyes. The corresponding gain with binoculars was a little less than 15 percent.

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The general conclusion to be drawn from the Brown University experiments is that the design of binoculars affects performance only to a minor extent within the usual range of specification of these instruments. Standard 7x50 binoculars, hand-held, are only about 15 percent less efficient than 10x70 binoculars mounted on alidades which yield optimal results under laboratory conditions. The point may be made, however, that even the minor improvements noted are significant wherever optimal performance at night is required.

The University of Pennsylvania experiments (46) were designed to evaluate some of the factors which served to detract from the theoretical value of telescopic instruments. Two such factors proved to be of considerable importance. The first of these was the misalignment of the exit pupils with the natural pupils of the eye. The extent of this misalignment was determined by photographing the observer's eyes, imaged in the objective aperture of the binocular. It was concluded that there was a loss of about 0.15 log units of range to be attributed to the average amount of this misalignment. Interestingly enough, the misalignment seemed to result primarily from movements of the eyes themselves rather than movements of the head.

The other factor which was analyzed in these experiments was that of angular tremor. Direct measurements of this angular tremor were made in the laboratory by a photographic technique and calculations were made of the probable extent to which this tremor would detract from binocular performance. This type of analysis accounted fairly satisfactorily for the loss due to tremor as calculated for the Brown University experiments. It was found that angular tremor was not greatly influenced by the fit or balance of the binoculars, but seemed rather to depend on external conditions of vibration and wind. Accordingly, it was concluded that provision should ordinarily be made for vibration-free rests for the elbows and for sheltering the observer from wind.

Detection at Daytime Levels of Illumination

Most of the data on frequency of seeing at high levels of illumination have been accumulated for the naked eye rather than for telescopic observations There would seem to be a definite need for research involving optical instruments along the lines of the naked-eye experiments recently reported by Lamar, Hecht, Schlaer, and Hendley (22).

In submarine warfare, the daytime detection problem is particularly acute when searching for targets by means of the periscope. It is standard practice to raise the periscope for such a short time that an adequate check search is impossible. A great deal of improvement on the use of the periscope for this purpose may be achieved by training the observer. Perhaps still more promising is the improvement of photographic means of observation. A rapid sequence of photographs is taken for later analysis after the periscope is submerged.

Improving the Discrimination of Contour

The mere detection of a target is but the first step in its observation by visual means. In order to recognize and examine the finer details of the target there must be a discrimination of outline or contour.

One of the few experiments on the accuracy of contour discrimination during the use of telescopic instruments was done at the Armored Medical Research Laboratory at Fort Knox, Kentucky (29, 32). This study was conducted under starlight conditions with a Landolt ring as a target. Standard 6x30 and 7x50 binoculars and also the 10x45 B. C. scope were used in this study. The factors of magnification, exit pupil, and objective lens diameter were considered for their effect on the distance at which the acuity test object was clearly observed. Some of the conclusions of this study in regard to night visual acuity were the following: (1) The 6x30 binoculars enabled an observer to recognize a target at approximately 3.5 times the range at which the unaided eye can recognize it under the same starlight conditions. (2) For the 7x50 binoculars, the corresponding figure is 4.75. (3) Over the limited range of these experiments, there is a direct relationship between magnification and the distance at which targets can be recognized. (4) The techniques of efficient night seeing for the unaided eye (dark adaptation, off-center vision, and scanning) also apply when using binoculars.

Pointing and Tracking

There is a considerable literature on the subject of pointing and tracking with telescopic instruments such as gun sights, mounted binoculars, rangefinders, etc. This literature is listed in the classified bibliography on visual research by Fulton, Hoff, and Perkins (10). We mention here only one set of experiments which bears directly on the characteristics of the optical instruments.

An article by Washer and Williams (28) describes some experiments on the precision of telescope pointing for outdoor targets. In these experiments, the telescope was trained upon a target and the cross hairs were set into apparent coincidence with the image of the target formed by the objective and seen through the ocular. The pointing was accomplished by prisms external to the telescope and located in front of its objective. Rapid observations were taken by the observer under various experimental conditions. The probable error of a single pointing was computed on the basis of these observations and was found to have an average value of 0.62 second of arc. The corresponding value for an indoor target was 0.24 second of arc. The relation of this study to problems of atmospheric distortion will be discussed below. It is sufficient here to note the author's belief that for magnification in excess of 20 diameters, there is no gain in the accuracy of outdoor pointing for subjects at great distances.[1]

Range and Height Finding

Radar and submarine echo devices have taken over the field of range-finding to such an extent that optical devices have now come to assume largely a stand-by function. There is a telemeter device in the submarine periscope which provides for measuring the height above the water of the masthead of a surface target. The accuracy of this device for the purpose of measuring the range is dependent upon a knowledge of the actual height of the masthead, and a small error in this figure may lead to a considerable error in determining the course and speed of the naval target. Further consideration of these devices will also be postponed to a section below.

Navigation

Problems of navigation are expected to become more critical as submarines extend their range of operations and as it becomes increasingly necessary to remain submerged for long periods of time. Attention should accordingly be directed to the extent to which the periscope may be used as an instrument for measuring the azimuth and elevation of celestial objects. For this purpose it is essential to provide a gyroscopic stable element for use in connection with the periscope. No research on this problem is known to the author at the present time, but the development of such devices may be in progress in connection with the current process of redesigning the periscope (**37**).

Concealment of the Observer

A submarine periscope is the chief representative of a fairly large group of optical instruments whose function, in part at least, is to enable the observer to see without being seen. Koenig (**21**) has listed and described a number of other telescopic instruments for this purpose. Some of these are to be used on land for the purpose of elevating the line of sight above the tree tops or other intervening objects. Special periscopes for use in aircraft have been developed and a foxhole periscope is also in use (**46**).

LIMITATIONS OF OPTICAL INSTRUMENTS

Atmospheric Conditions

It is obvious that even an ideal telescope operated by a good observer cannot function under unfavorable atmospheric conditions. This is one of the reasons, of course, for the development of radar and other means for the detection and identification of targets. It need hardly be said, however, that for purposes of detailed examination of a target there is no substitute for visual observation.

Target Detection

The state of our knowledge concerning the effect of atmospheric conditions upon detectability of targets is relatively highly developed. Much of this development occurred in connection with OSRD projects during World War II (**54**).

Hardy (**13, 14**) has outlined the manner in which the principles of atmospheric attenuation apply to the performance of telescopes. It has long been known that the apparent luminance of a target decreases

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[1] It might be mentioned here that the problems of pointing and tracking are importantly related to the type of reticle pattern to be used in the gun sight or telescope. See the discussion of this topic that appears below.

exponentially with the target distance because of the atmospheric attenuation. This is in conformity with Koschmieder's law, which may be written as

$$C_R = C_0e^{-\beta R}$$

where C_R is the contrast of the target at range R, C_0 is the contrast at range zero, and β is a coefficient of attenuation. Certain instruments are available for the direct determination of β. A value of approximately .02 represents the threshold condition of C_R. On the basis of these facts, it is possible to predict the effective range of visual observation for values of β corresponding, for example, to very clear, hazy, or foggy atmospheric conditions. As we have noted above, it is possible under ideal atmospheric conditions to extend the effective visual range by the simple process of increasing the magnification of the telescope. Hardy has shown that, under ordinary atmospheric conditions, the magnification must be great enough to compensate for the reduction in contrast of the target as well as the reduction in size at great distances. Hardy's analysis reveals that the increase in maximum range is small unless the atmosphere is very clear and that, for this reason, low power telescopes ordinarily give as much increase in range as telescopes of higher power. One conclusion which emerges as a result of his analysis is that it is futile to compare optical aids for quality and precision by means of field tests at maximum ranges. The optical quality of instruments should be measured indoors at relatively short ranges where the state of the atmosphere is not a factor.

Duntley (**7, 8**) has summarized the principal factors involved in the visibility of distant objects, making use of the Koschmieder relationship and applying the results of the Tiffany Foundation experiments on contrast (**1**). Duntley has developed a series of nomographic charts for predicting the limiting range at which a uniformly luminous object can be detected by unaided vision. It is possible to enter these charts with data on meteorological range, contrast, luminance, and target area and thereby predict the liminal target distance. By the use of certain corrections to the brightness and area factors, it is possible to use Duntley's charts to predict visibility along inclined paths of sight. This use of the charts is of course required for observations of aircraft from submarines and vice versa.

The maximum distance at which a target may be seen is predicted by the above nomographic charts for excellent observers who are forced to judge whether the object is present or absent. Consequently, the ranges so predicted are to be regarded as maximum values which are not always attained in practice. Under some circumstances, it may be desirable to arrive at an estimate of the range at which the *average* observer is *confident* that he has indeed seen the target. In this case, Duntley suggests dividing the inherent contrast of the object by two before entering the data on the chart. This procedure is admittedly for expediency only and has no quantitative justification.

Coleman (**39**) has extended the usefulness of the nomographic visibility charts by making provision for the variables associated with telescopic instruments. Coleman's treatment enables one to predict the detection range for an object using a telescopic instrument whose characteristics are known. The particular characteristics so employed are (1) magnification, (2) contrast rendition, (3) light transmission, and (4) exit pupil size.

The factor of *magnification*, M, increases the apparent magnitude of each dimension linearly and hence increases the apparent area of the target by a factor of M^2. Therefore, the inherent target area given by the chart is replaced by an apparent area which is M^2 times as large.

Contrast rendition is given by the relation,

$$\text{contrast rendition (\%)} = \frac{\text{contrast of the image}}{\text{contrast of the object}} \times 100.$$

In using the charts, this factor is used to correct the inherent contrast of the target by the amount of the contrast rendition.

Light transmission is defined as the ratio of the brightness of the telescopic image to that of the naked eye image. This value, determined photometrically, may be applied as a correction for the value of luminance or brightness with which the nomographic chart is entered.

The *size of exit pupil* is a determiner of the apparent brightness level. Since exit pupil sizes are given in diameter units, it is necessary to square the ratio of the exit pupil size to the size of the natural pupil in order to arrive at the appropriate correction to be used in the nomographic charts. Average pupillary diameters for given values of luminance are given by the experiments of Reeves (**24, 25**) and others. This factor, together with a minor correction for the influence of the Stiles-Crawford effect, is incorporated into the charts. Numerical examples for the solution of problems on the liminal detection range are given.

Coleman and Verplanck (**5**) have reported field tests of the detection ranges of objects viewed with telescopic systems from aboard ship. Approximately 80 telescopic systems of 18 different designs were used in these experiments. A comparison was made between the computed performance of each instrument, as arrived at from the nomographic charts devised by Coleman by the method outlined above, and the field performance as actually measured in these tests. A very satisfactory agreement was found between the computed and predicted values under the conditions of this experiment. It is concluded by the authors that for the mere detection of objects, it is possible to predict fairly accurately the range at which they are visible knowing only the physical measurements necessary for the use of the nomographic charts. The problem of recognition unfortunately is a more difficult one and is not amenable to this type of prediction.

Target Resolution and Recognition

The distortion of target images by atmospheric factors is of importance in the detailed examination and recognition of objects. It is well known that one of the most severe limitations of telescopic systems is to be found in the extent of shimmer caused by differential refraction of light over the optical path from the target to the telescope. The extent to which shimmer causes deviations in the apparent position of points on the target has been measured photographically by Riggs, Mueller, Graham, and Mote (**26**). This report shows that when a large amount of atmospheric shimmer is present, the average deviation in position of a point on a telescopic image is of the order of 2.4 seconds of arc, and that the maximum deviation may amount to 12 seconds or more. The resulting distortions of the over-all target image are shown by the instantaneous photographs upon which this report is based. Measurements were also made of the degree to which the images of two targets were similarly distorted at the same instant of time. It was found that, for targets which were very close together, the images suffered the same kind of distortion, but that the similarity became less marked as the targets were separated laterally by a greater and greater distance. These measurements suggest that, because the value of telescopic magnification is diminished by the fact that the apparent shimmer of a telescopic image is directly porportional to the magnification, low magnification is optimal under conditions of marked shimmer. Analysis shows this to apply to the case of stereoscopic rangefinder operation as well as to simple problems of target resolution.

Pointing and Ranging

In the article by Washer and Williams (**28**) to which reference was made above, the distortion of the telescopic image by the atmosphere was studied for its effect upon the precision of telescope pointing. The method used in this study was to attempt to achieve a coincidence between distant target and cross hairs of a telescope. The authors point out that this task becomes difficult when shimmer is present because it involves deciding upon the mean position of a constantly oscillating target image and setting the cross hairs thereon. For outdoor pointing, the probable error of a single setting was .62 second on the average, whereas for indoor pointing the corresponding figure was .24 second. At the end of the article is a summary of corresponding figures reported by other authors under a wide range of experimental conditions involving many different values of magnification. The average value for pointing precision given by these other investigators agrees fairly closely with those given by Washer and Williams. Washer and Scott (38) have reported an experiment in which a straight line object at the range of the distant target was substituted for the cross hairs. Telescopic magnifications of 42×, 85×, 98× and 192× were used. The probable error of a single pointing in aligning this object with the target had an average value of .11 second of arc. Comparable measurements with the usual telescope cross hairs yielded a corresponding probable error of .52 second. This is another demonstration of the extent to which atmospheric factors reduce the accuracy of telescopic observation.

A British report (48) gives the results of experiments on the relation between magnification and mean consistency in performance with stereoscopic and coincidence rangefinders. An important conclusion of this report is to the effect that atmospheric shimmer renders high magnification no more effective than low even under conditions of excellent visibility. This finding points up the fact that there is very little relationship between the liminal range of detection that may be increased by magnification, and errors of observation resulting from atmospheric shimmer that may be independent of magnification.

Optical Defects

It is obvious that defects in an optical instrument will limit the efficiency of telescopic observations. Coleman and Harding (4) have measured primary astigmatism, coma, and spherical aberration for a number of telescopic instruments, using high-contrast test objects of the Foucault type. It was found that loss in instrument resolving power was considerable even for aberrations of moderate magnitude. Loss in resolving power was greatest for astigmatism and was greater for test objects of low contrast than for those of high contrast.

For a detailed discussion of optical defects, aberrations, stray light and other problems of the optical design, any standard work on optical design such as that of Conrady (6) may be consulted.

The Human Observer

Because of human factors in the use of optical equipment, even a perfect telescope used under ideal atmospheric conditions can never be expected to provide faultless observation.

The Eye

The eye is itself an optical instrument characterized by loss due to aberrations, stray light, etc. Furthermore, it is an anatomical structure whose function is limited by normal physiological conditions such as physiological nystagmus movement and the properties of the retinal mosaic. These factors are well described in articles by Byram (2, 3) and by Jones and his co-workers (17, 18, 19, 20).

It may probably be assumed that the usual clinical tests of vision are adequate to screen out personnel whose eyesight is so poor as to prevent them from being at least potentially good observers with optical instruments (52). Having made this assumption, we shall mention a few of the precautions which should be taken in regard to the use of the eye for this purpose. The length of time during which the eye is in constant use has an important influence on the efficiency of observation. This length of time depends somewhat upon the difficulty of the observations which are being made. For a monocular instrument, such as a periscope, a period of 30 minutes is commonly accepted to be sufficiently long for continuous observation. On night lookout duty, with the use of binoculars, the time may be extended to as much as four hours, but this observation is essentially intermittent in character. The observer is not maintaining an optimum level of performance every moment of the time. It should be emphasized that the limiting lengths of time cited in this paragraph are the reflection of military experience only and are not based upon actual research in regard to the efficiency of observer performance.

The matter of adjusting optical instruments to the eyes of individual operators deserves comment. One aspect of this adjustment, namely, the movement of the eyes in relation to the oculars, was mentioned above in connection with the experiments of Hartline (46). The provision of rubber eye guards and alidade mountings may be expected to aid somewhat in securing the desired alignment between the eyes and the oculars.

Another aspect of the alignment problem for binocular instruments is the adjustment for interpupillary distance. The solution of this problem requires first that the interpupillary distance of each operator be accurately measured; second, that the instrument itself have an adequate scale of interpupillary settings; and third, that the operator be able to set the instrument to match his own interpupillary distances. A series of articles by Kappauf, Brogden, Imus, and others (10, Items 3883–3887) describes an instrument known as the NDRC interpupillometer that achieves a considerable improvement over earlier devices and that may be recommended as suitable for the task of measuring interpupillary distance of military personnel. The problem of adjusting telescopic instruments to the interpupillary distance of the observer is also discussed in this series of articles.

Further evidence on the reliability and validity of the NDRC interpupillometer is given in a series of photographic determinations made in the course of experiments at Brown University on the design of opaque reticles (50). Photographs were made of the eyes of the observer by a special device described in reference *Q* of that report. It was found that the proportion of individual interpupillary distances measured within plus or minus 0.2 mm. on the test-retest was .68 on the photographic device and .70 on the NDRC interpupillometer. This degree of reliability is believed to be satisfactory for the usual forms of binocular military instruments. The difference between photographic and interpupillometer measurements was also found for each subject. The validity of the interpupillometer is attested by the fact that all of these differences were considerably less than one millimeter, and their average was not significantly different from zero.

That the adjustment for interpupillary distance is a somewhat critical one for optimal observer performance is attested by some experiments of Hartline (33) on binoculars and some heightfinder experiments summarized by Fernberger (9).

A factor which has apparently not received adequate notice is to be found in the change in refractive power of the human eye in dim and bright light. Wald and Griffin (27) have studied this phenomenon with particular reference to spherical aberration, chromatic aberration, and state of accommodation of the eye in dim and bright light. A surprising result of their experiments on accommodative power was the finding that the eye seems to be in a condition of relatively fixed focus in dim light. Furthermore, the particular state of accommodation in dim light is quite different from one observer to another. Consequently, the focus of binoculars for night vision becomes a rather critical factor in the detection of targets and errors in focus are not compensated by the accommodative mechanism of the eye. It is apparently necessary to determine the refractive power of the eye of each observer in dim light in order to specify the setting of the eyepieces which will yield minimum threshold for night observations. The change in diopter settings in going from photopic to scotopic levels averages about −0.5 diopter. Although individual observers may show some considerable departure from this value, it should in general be of service to instruct observers to use more negative settings.

Higher Visual Functions

It is well known that among observers whose eyes appear to be normal there is a wide range of individual differences in the efficiency of observation. This fact appears to be particularly true in the use of optical instruments which call upon the individual's ability to make fine discriminations and to make correspondingly fine adjustments in the recording mechanism of these instruments. During World War II, a considerable amount of research was devoted to the selection and training of operators for such instruments as rangefinders, gun sights, and various tracking devices. This literature is covered in the standard bibliographies of the classified material which appeared at that time (**10**, items 3610–3622, 3776–3782, 3888–3897, 4031–4042, 4065–4081, 4760–4851). It would indeed be a difficult task to summarize these reports except in a most general fashion. It appears that for some particular visual tasks, as for example that of stereoscopic rangefinding, special abilities are required and selection must be made of a relatively small percentage of all the persons with the necessary qualifications of eyesight, intelligence, etc. For other problems, such as that of the night lookout who uses binoculars, it is the opinion of many persons that nearly everyone with normal vision is capable of a creditable performance after adequate training and under proper motivation. (See Chapter A.)

Comparison and Tie-In with Unaided Vision

Unaided binocular vision may be regarded as observation with a binocular instrument of unit power, base length, brightness, contrast, exit pupil, etc. Various optical instruments are able to provide an improvement in the first two of these factors, but not in the last three (**14**). Thus, it is possible by the use of instruments to obtain a larger image having an exaggerated stereoscopic view in terms of parallactic angle, but it is not possible to increase the field brightness, the target contrast, or the exit pupil (**16**) beyond those obtaining for the unaided eye. As noted above in the section on telescopic instruments, it is not possible to make much improvement in the range at which targets may be detected or recognized under adverse meteorological conditions. Optical instruments, then, are particularly superior to the naked eye in the detection and examination of relatively small, distant targets under conditions of good visibility.

Comparison and Tie-In with Radar, Sonar, Infra-Red Detection, Etc.

New devices are being built into the periscope of the modern submarine so as to supplement and extend the visual observation of targets. It is believed that research is now being conducted on the most advantageous arrangement of these devices from the point of view of the operator and the skipper of the craft. The fact that these other devices are subject to enemy interference and the fact that visual search and recognition is still the most satisfactory under favorable weather conditions seem to make it certain that optical instruments will continue to play a dominant part in military observation for some time to come.

Problems of the Design of Optical Instruments

Optical Aspects

The design of telescopic instruments demands compromises in which preference is given to those characteristics which are most desirable for the particular task to be performed by the instrument. Such factors as magnification, exit pupil size, diameter of field, and field brightness represent desirable factors which cannot all be present in optimal amount in any one instrument. Exit pupil diameter, for example, is inversely proportional to magnification, as also is diameter of field. By increasing the diameter of the objective lens, it is possible to effect a proportional increase in exit pupil diameter but only at the expense of creating a larger and heavier instrument. In the case of a rangefinder, a similar problem exists in relation to the base length of the instrument. With regard to the correction of aberrations, the limitations of expense and the number of air-glass interfaces must be borne in mind. In short, every optical instrument represents a compromise which is arrived at after careful consideration of the order of importance to be attached to the various factors mentioned above.

The particular instruments which have been used most constantly aboard submarines are the attack periscope, the larger search periscope, and mounted binoculars for use on the deck.

Periscopes

Each of the periscopes has usually been provided with interchangeable magnifications of 1.5× and 6×. It is said that the 1.5× is equivalent to unit power because of an illusion of smallness which is characteristic of vision through a narrow tube (16). The relatively low magnifications have been arrived at from the following conclusions: (1) The most important targets are relatively close by in a submarine attack; (2) the problem of vibration has always been a serious one, and its influence upon the telescopic image is directly proportional to the magnification; (3) the size of the objective lens must be kept small because this is the chief determinant of the diameter of the head of the periscope; (4) since the periscope is often used for check search purposes, a relatively large true field is necessary; (5) a large exit pupil helps to assure an adequate brightness transmission for night observations.

A common form of periscope covers a true field of 8.7° with a magnification of 6×. Exit pupil diameter is 4 mm. and the eye relief is 20 mm. The light transmittance is 24 percent. A power of 1.5× is also possible by use of a supplementary low power Galilean telescope in the head of the instrument (16).

Mounted Binoculars

The binoculars used on the deck of a submarine are provided with antivibration mounts with an arrangement for transmitting the bearing of a target to the control room below. The binocular itself is a 7x50 instrument sealed against moisture and pressure. From the point of view of optimal performance at night, it would seem that better results might be secured from a 10 or 20 power instrument (35). It is true, however, that for purposes of detection of distant targets, the 6x50 instrument is only slightly inferior (about 15 percent in terms of range) to the instruments of higher power (46). Possibly the large size of instrument which would be necessary to secure magnification of 10× to 20× powers may be objectionable from the point of view of sealing against moisture. In any case, the mounted binocular problem may become unimportant because of the fact that the new submarines will not surface so often.

Devices Extending the Panoramic View of the Periscope

It seems likely that radar will be depended upon for search and detection to such an extent that the use of the periscope for this purpose may become less common. Nevertheless, it may be of interest to consider possible devices for extending the field of periscopic instruments so as to permit search for aircraft and surface targets. One solution to the problem is to provide a double isosceles prism (16) for scanning through a wide angle in a single plane. It would seem possible that some such device coupled with rapid motion-picture photography might provide the necessary coverage of the sky in a relatively short period of observation.

Optical systems have also been developed for obtaining a panoramic view of the entire horizon for surface-scanning purposes. Koenig (21) has described an attachment to a periscope known as a *Ringbildsehrohr*. With this device, one obtains the usual periscopic view in a single direction at the center of the field, but the field is surrounded by a ring containing a panoramic view of the entire horizon. The image in this ring is a distorted one secured by the use of an annular lens in the periscope head. This device, now obsolete, was suited only to the rapid detection of nearby surface targets.

Monocular vs. Binocular Viewing

It is well known that, other things being equal, it is preferable to use binocular rather than monocular viewing for telescopic observations. A recent discussion of this problem by Riggs (40) has summarized some of the laboratory data on the extent of binocular summation. There is no general agreement on the extent of such superiority, values ranging from 10 percent to 50 percent having been reported in various investigations. Binocular viewing seems to be particularly advantageous for night vision and not so much so in the daytime when the field brightness levels are high. A value of 15 percent has been noted above for the superiority of binocular over monocular viewing as reported in the Brown University experiments (46). Binocular instruments were found to have a superiority of at least 10 percent at night in the field tests conducted at New London (35).

The problem of monocular vs. binocular viewing has been discussed specifically in connection with eyepiece design for periscopes. It is known that German periscopes have used an optional binocular eyepiece for some time. It is contemplated that such an eyepiece may be incorporated as an improvement upon our own Navy periscopes (37). The particular problem here is one involving the loss of light associated with the use of a binocular eyepiece. When this eyepiece is in use, the field for each eye has only about 40 percent of the brightness of the single field of a monocular eyepiece. This loss in brightness of field is probably of no importance for daytime viewing, since visual acuity and probability of detection are not materially reduced by a reduction in brightness at these high levels of illumination. At night, however, a 60 percent reduction in brightness might very well be more significant than any gain which might be expected from the use of a binocular eyepiece. The most advantageous field performance calls for a device for shifting rapidly from binocular to monocular vision, the latter arrangement being primarily for night observations.

Reticle Pattern

Nearly every telescopic instrument of military usefulness is provided with some form of reticle which appears as a scale or set of cross hairs in the plane of the target image. The specific design of reticles is largely dictated by the use to which the instrument is to be put. Certain considerations, however, apply to reticles in general and these will be discussed in the paragraphs which follow.

Obscuration. It is obvious that the lines of a reticle should be neither so thick that they obscure significant amounts of the target image, nor so thin that they are not clearly visible to the observer. An optimal thickness of line has been found in practice to be of the order of two to five minutes of arc in terms of visual angle.

An alternative solution to the problem of obscuration is to view the target in a clear portion of the reticle field so that no important obscuration is possible. British investigators (43, 44, 45) have recommended that a clear circular region be provided, with a minimum diameter of 10 mils of apparent field. These reports have raised the interesting point that small targets are not only hidden by the opaque lines on reticles but are also obscured for a considerable region surrounding each of the lines. This phenomenon is accounted for as a suppression of target-to-background contrast. The extent of such obscuration may be as much as 22 mils of apparent field.

Glare. In the case of illuminated reticles, a problem corresponding to that of obscuration is also present. This is the problem of veiling glare. The degree of glare has been analyzed in a British report (30) in which it is stated that glare is determined by the reticle contour, its brightness, and its nearness to the target.

A study at Brown University (49) revealed that precision of performance in a stereoscopic visual situation decreased as reticle illumination increased under conditions where the target was stationary. Stereoscopic cues are lost at high levels of reticle illumination, and this is particularly true for targets which show fine detail. The above statements in regard to the adverse effects of illumination do not hold true for targets which demonstrate tracking-error movements. Presumably this is because the relation of target to reticle is constantly changing and performance is relatively poor even under the best conditions.

Recommendations for Specific Reticles. Specific reticle designs have been arrived at for the purpose of minimizing the factors of obscuration and glare, at the same time achieving the type of measurement for which the particular instrument is designed. The reticle field for a gun sight was given considerable study in a project of the Applied Psychology Panel, NDRC (31). In this study, three particular designs of gun sight reticle were submitted to field tests. One of these three designs was demonstrated to be superior to the other two. The center of this reticle field was delimited by a circle which was 18 mils in diameter of apparent field or 3 mils in true field diameter at 6×. Concentric circles having true field diameters of 9 and 15 mils were also provided and vertical and horizontal lines extended out from the 15 mil circle in the direction of the edge of the field. This pattern offered good opportunities for stadimetric range determinations and was superior to the other two on the basis of tracking errors. An "amplication factor" of 4.2 for this reticle indicated that the gun order error was approximately only four times the sighting error and was smallest for this reticle.

The primary basis on which the gun sight reticle patterns described above were evaluated was an extensive series of experiments in which both aerial and stationary targets were used. The tracking error of the operators was scored under conditions where the operators were on stationary platforms and also under conditions where the platforms were moving to simulate the pitching and rolling of a ship. It would seem that the conclusions drawn from this study would have very general application to the construction of reticles for many types of sighting instruments. The specific reticle described above as the most suitable represents a pattern which might be used with minor modification in many other instruments.

The problem of the design of stereoscopic reticles is a particularly specialized one because of the extraordinary acuity of stereoscopic depth discrimination (12). One consequence of this high degree of acuity is the necessity for very great care in the manufacture of left and right reticles whose similarities and differences are easily detected in stereoscopic vision. When the left and right reticles are identical, their pattern defines a plane at a certain apparent distance from the observer.

A stereoscopic rangefinder makes particular use of the plane of depth established by stereoscopic reticles. In this case provision is made for adjusting the image of the target so that it appears to be located on the plane of reference defined by the reticles. After this adjustment has been made, the range of the target may be read directly from a dial on the instrument. A series of experiments was conducted at Brown University to select patterns of stereoscopic reticle which would be most suitable for the rangefinding task. With regard to opaque reticles (that is, reticles which appear dark against the background of the target) the following conclusions were arrived at (50): (1) Height adjustment errors should be minimized by the use of vertical lines exclusively in the reticle pattern. If this recommendation is followed, differences in the vertical alignment of target and reticle for the two eyes will not greatly interfere with stereoscopic depth discrimination. (2) "False fusion" should be prevented by the use of reticle marks separated one from another by unequal distances. Another method of preventing "false fusion" is to include fore-and-aft marks of smaller size and different location from the principal vertical lines of the reticle. (3) A single pair of such marks whose stereoscopic distance from the remainder of the reticle amounts to 25 to 50 UOE may be recommended. (4) A maximum of five vertical lines should be used as the principal component of the reticle. (5) The thickness of reticle lines should not exceed nine minutes of apparent field.

Following the above recommendation, a reticle design was submitted for possible use in future stereoscopic rangefinding devices. This design involved five vertical lines extending for 20 mils of true field in the horizontal plane. Fore-and-aft marks were provided at a stereoscopic distance of 25 UOE from the plane defined by the five principal marks. The principal marks had a height of four minutes of true field with the exception of the central mark which was differentiated by having a height of five minutes. The fore-and-aft marks had heights of 1.50 and 1.25 minutes respectively. The thickness of all marks was 0.20 minutes of true field. The principles described above were arrived at and validated by laboratory tests. Field tests of the results of these experiments have not yet been conducted.

With regard to the design of illuminated reticles, certain other principles may be stated in addition to those which apply to the opaque reticles. Six patterns of illuminated reticle were evaluated in a series of experiments at Brown University (49). The conclusions in regard to the brightness of the illuminated pattern have been stated above in the discussion of glare. The remainder of the conclusions from these experiments are similar to those arrived at in the report of opaque reticles. Vertical line patterns were again found most resistant to errors due to faulty height adjustment. "False fusion" was preventable by the use of fore-and-aft marks. An alternative method of preventing "false fusion" was in the use of unequal spacing of the vertical lines of the main pattern. Certain suggested patterns, including one designed to appear as an illuminated window and one taken from a captured German instrument, were found not to measure up to the standards set by the results of the experiments. The conclusion was drawn that, if personnel are instructed to use low to moderate reticle illumination, performance is likely to be as good as that obtained by opaque reticles. Illuminated reticles, of course, have the advantage that the brightness of the reticle lines may be adjusted to bear an optimal relation to the brightness of the target over the entire range of daytime and nighttime operating conditions (47).

Physical Aspects

It is not the purpose of this report to discuss in detail the design and construction of specific optical instruments. Some of the references (11, 16, 21, 46) may be consulted here. We must note, however, that changes are being made in these instruments, and that they will bring about new problems of psychological and physiological nature because of the new demands placed upon operating personnel.

The Kollmorgen Optical Company and Bausch and Lomb Optical Company are currently working on improvements on submarine periscope design. The human factor in the design and layout of the periscope has been considered by a project of the Division of Bio-Mechanics of the Psychological Corporation in New York (37). This project, working at the Special Devices Center of the Office of Naval Research, has submitted recommendations for certain aspects of the design of the periscope which are calculated to improve operator performance. The periscope is now designed to provide a convenient means of still and motion-picture photography, and an any-height feature which enables the operator to sit or stand at a constant height in relation to the periscope eyepiece. The periscope is now trained by means of a motor which drives it around to any desired bearing. An optical binocular eyepiece may be used alternately with the conventional monocular eyepiece. Many new controls and dials are necessitated by the improvements to the periscope, and the project has made recommendations in regard to their location and illumination.

Certain physical problems of design must be solved before psychological and physiological performance can be evaluated. Perhaps the most important of these in submarine warfare is that of the vibration of the periscope. In the past, the periscope has not vibrated excessively when the submarine was stationary or was proceeding at a relatively slow speed. At a speed of six to eight knots, however, the vibration becomes quite objectionable and at higher speeds it becomes so serious as to prevent periscopic observation entirely. The consequence of this is that the old-style periscope is useless in the modern submarine equipped with a snorkeling device. The periscope must be redesigned and strengthened to cut down on the vibration at high speeds. Other problems of a physical nature that must be met are those of draining the water from the window at the head of the periscope and the prevention of the formation of fog as the periscope is raised for observation.

SUGGESTIONS FOR FUTURE RESEARCH ON THE HUMAN FACTOR IN THE USE OF OPTICAL INSTRUMENTS

General Suggestions

In general, the improvement of operator performance may be attacked along the following lines: (a) through the selection of personnel, (b) through the training of persons selected, and (c) by adapting instruments to their operators.

Selection of observers. This problem was discussed briefly above. It was noted that the usual clinical tests were adequate to select personnel who were capable of good operator performance as judged by their visual acuity. We must note, however, that some of the particular tasks imposed by the use of optical instruments require very special abilities which may not be found in any large percentage of potential observers. It has hitherto been necessary under these circumstances to develop correspondingly specialized tests for the selection of personnel having these special abilities. For example, tests of candidates for height finder training were developed and administered during World War II (51).

One of the very practical problems in connection with this type of selection is the problem of how to identify persons who possess these special abilities throughout their service careers. It would seem that some effort should be made to indicate on a man's service record the special abilities and disabilities in regard to vision and other functions. It would seem highly desirable that each man be given a permanent record on which would be included data on his visual acuity; stereoscopic ability; night vision; extent of color blindness, if any; etc. It is recognized that such a record involves possible loss and misuse, but it would seem that these practical difficulties might be overcome in the interests of using the man best suited to the particular job of observing.

Training of observers. Training may often be accomplished by the use of special training devices which more or less adequately simulate the field situation. Training in the use of optical instruments has been carried on rather extensively in the stereoscopic rangefinder schools. One general conclusion about training is to the effect that a positive transfer of training occurs only when the similarity to the field situation is a close one. Consequently, the development of new optical instruments always necessitates the parallel development of training instruments bearing a great similarity to the instruments actually used.

In submarine warfare, a training device is the Attack Teacher Marks 3 and 7, developed for the U. S. Naval Submarine School at New London, Connecticut. The use of the attack periscope is simulated by Mark 38 and Mark 40 periscopes in connection with this trainer.

Adapting instruments to the human operator. This approach is exemplified in the Psychological Corporation's project referred to above (37) In the past, it has unfortunately been true that new devices have been engineered without consultation with qualified psychologists and physiologists on the most favorable design from the point of view of the observer. It is certainly to be hoped that this situation will be avoided in the future, because it is critical to know when the demands of modern instruments approach or exceed the limits of human ability.

Sponsor please note

Specific Suggestions

The survey of research on the use of optical instruments as presented in this paper has raised a number of specific questions which might be the subject of further experimentation. Accordingly, we shall review the survey and high-light topics which in the author's opinion should be investigated further at this time.

Most of our present fundamental knowledge of visual acuity, contrast discrimination, etc., as reviewed in Chapter 1, is based upon studies of the naked eye rather than studies in which telescopic devices have been employed. It would seem desirable to conduct more studies of direct visual discrimination through optical instruments. It would seem particularly desirable to set up an experimental procedure for studying the use of optical instruments systematically, covering a wide range of magnifications, exit pupil diameters, and field sizes and brightnesses. Monocular and binocular instruments should be included.

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In a comprehensive series of such experiments, emphasis might well be placed on measures of visual contour recognition or acuity, since existing data are heavily weighted on the side of mere detection (and the detection of targets is a function more and more of radar and other non-visual devices). It would be desirable to set up a series of experiments in which the Landolt ring or other acuity test object would be observed with telescopic instruments over short ranges, preferably indoors. This series of experiments would extend the observations of the type made at Fort Knox (29, 32). Such experiments are needed to establish optimum values of magnification, exit pupil diameter, etc., for maximum resolution of the target both in the daytime and at night. Hartline (46) has listed specific recommendations for future research in the use of binocular telescopes. His suggested experiments would round out the experiments conducted at Brown University, Dartmouth College, and the University of Pennsylvania. All this proposed research should be conducted in a sufficiently general and comprehensive form so that when new types of telescopic instruments are contemplated, it will be possible to predict fairly well the level of performance to be expected of a given optical design. Experiments on particular binoculars or telescopes should be avoided in favor of experiments on a single generalized form of instrument whose optical characteristics could be varied widely as suggested above.

With regard to atmospheric optics, again the picture is fairly satisfactory from the standpoint of mere detection. The application of the Koschmieder formula by Hardy, Duntley, Coleman, and others has enabled us to predict visibility quite satisfactorily over a wide range of atmospheric conditions. The problem which seems to call for further work is that of resolution rather than detection. It is, therefore, suggested that a similar series of experiments and calculations be addressed to the resolution problem.

There is ample evidence that detection and resolution are very differently affected by a given set of atmospheric conditions. The specific effects of optical shimmer are a good example here. A mirage is an extreme example of the appearance of a target where visibility may be excellent but target location, size, shape, etc., may be highly distorted. Less extreme examples are to be found in the similar difficulty of recognising or sighting on a distant target which is subject to atmospheric shimmer. It seems conceivable that some convenient device may be developed for measuring the extent of atmospheric shimmer. Having this device, it would be possible to make a set of nomographic charts resembling the existing ones for determining the meteorological range. The new charts would be for the purpose of determining the resolution distance or the range for which a given degree of resolution might be predicted. After further research on the distortion of target images by the atmosphere, it might appear that such nomographic charts are impractical or even impossible to develop, but an empirical test of this idea should be worth making.

It was noted above that some experiments have recently been reported (26) in which the effect of atmospheric shimmer has been analyzed in terms of the telescopic image. Plans are now being made for more comprehensive studies of such atmospheric conditions. The Daniel Guggenheim Airship Institute of Akron is currently engaged in a study of atmospheric shimmer as a part of a much more general program on meteorological conditions at various heights above the ground (41, pp. 13–23). A series of experiments planned more directly to evaluate the effects of atmospheric shimmer is to be conducted at Roscommon, Michigan (41, pp. 36–40; 40, pp. 101–108). The technique of motion picture photography is to be used in evaluating atmospheric attenuation, and observations will be made simultaneously of targets having various values of contrast as seen against the sky. Distances up to 30 miles will be included in this very extensive series of observations.

While we have indicated above that the detection problem is no longer so acute as it has been in the past, it nevertheless is still one which might bear some future study. The Tiffany Foundation experiments (1) and the experiments which have stemmed from a study of the Koschmieder formula (7, 8, 13, 39) have been concerned with stationary or slowly moving targets. There is a need for similar data on the rapidly moving targets involved in aerial warfare. Ludvigh

(23) has recently advanced a systematic treatment of the relation between visual acuity in observing a moving target and the angular velocity of the target (for data, see Chapter 1). His reasoning "explains the large number of cases of inability to recognize moving objects when they are moving slowly enough so that they can actually be seen." In the submarine service at the present time there seems to be a feeling of the hopelessness of detecting enemy aircraft through periscopic observation and a tendency to regard radar as being the only device which might be adequate to this task. Possibly the specific modes of observation suggested by Ludvigh's analysis may help to improve the periscopic observation of moving objects.

On the side of anti-submarine warfare, the detection problem is still of greatest importance. Unfortunately, there seem to be no significant data on the effect of atmospheric conditions on the ability to detect submerged objects. The problem has now been recognized to be an important one, and a beginning has been planned (42) for a series of experiments on the state of the sea as well as the air as they influence the ability to detect objects which are submerged below the surface. Instruments and quantitative data appear to be wholly lacking as yet. Ludvigh's analysis may apply equally well to the problem of aerial search for submarine targets, since it may be adapted to the situation of a rapidly moving observer with relatively stationary targets.

Summary and Conclusions

Optical instruments of importance in undersea warfare have the general purpose of aiding the eye in the detection and examination of relatively distant objects.

Laboratory and field tests, briefly described in the present paper, have been most valuable in improving this function by evaluating the following topics: (1) Optimum physical characteristics of telescopes, such as magnification, exit pupil and type of mounting, particularly for nighttime detection of targets. (2) The limiting effect of atmospheric conditions on the detectability of targets. (3) The comparative values of monocular and binocular viewing. (4) The problem of adjusting the focus and interpupillary distance. (5) The design of the reticles in various forms of sighting and measuring instruments.

The following topics have been somewhat less adequately explored by experimental studies: (1) Optimum physical characteristics of telescopes for daytime use, particularly in the detailed examination and identification of targets. (2) The limiting effect of atmospheric conditions (especially atmospheric shimmer) upon the detailed examination of targets. (3) The selection and training of operating personnel. (4) The human factor in new developments in the design of instruments such as the periscope.

Very little systematic research has been accomplished on the following topics: (1) The use of optical instruments in observing rapidly moving targets. (2) Influence of the state of the sea on the detection and examination of submerged objects by the use of optical instruments.

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