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A TECHNICAL REFINEMENT OF THE VERNIER OPTOMETER

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However, a vernier optometer design provided to us by Dr. Robert Hennessy, of Monterey Technologies, Inc., did not reliably produce accurate results, at least as it was implemented at our laboratory. We saw a number of ways to improve the design of this vernier optometer. We believe we were successful in this endeavor and describe our new design here.



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SUMMARY PAGE

THE PROBLEM

The need for precise lens accommodation to bring visual targets into sharp focus on the retina is far more urgent at night, when contrast is very low, than in bright daylight. However, it is at precisely this time that many individuals become myopic and further reduce the quality of an already poor visual image. For pilots flying at night, this phenomenon can mean the difference between life and death. A reliable screening instrument capable of measuring the refractive state of individuals in the dark could, therefore, provide useful preventive information. Such an instrument should be simple, easy to use, and produce accurate results within a short period of time. Currently, much research in the area of "dark focus" has relied on the laser-Badal optometer. This device is simple and produces accurate results. It is, however, quite difficult to use in practice. Some individuals are completely unable to produce data with this device. An alternative optometer uses polaroids and a vernier task, hence the name vernier optometer. This device is simple to both construct and use. However, a vernier optometer design provided to us by Dr. Robert Hennessy, of Monterey Technologies, Inc., did not reliably produce accurate results, at least as it was implemented at our laboratory. We saw a number of ways to improve the design of this vernier optometer. We believe we were successful in this endeavor and describe our new design here.

FINDINGS

1. The data taken from a vernier optometer are sensitive to the chromatic content of the light source used and/or any chromatic aberrations present in lenses. This problem can be avoided by using a monochromatic light source.
2. In a recently reported comparison between our first Hennessy-designed vernier optometer and a laser-Badal optometer, the two instruments had a mean discrepancy of almost 3 diopters. In a similar comparison study between the optometer described here and a (the same) laser-Badal optometer, the mean discrepancy between the two instruments was less than 0.1 diopters.
3. The mean standard deviation of data taken from the vernier optometer described here is smaller (0.26 D) than the mean standard deviation of the equivalent data taken from the laser-Badal optometer (0.32 diopters).
4. The mean dark accommodation of the subjects was 1.131 diopters of myopia for data taken from the vernier optometer described here and 1.036 diopters of myopia for data taken from the laser-Badal optometer (uncorrected for the chromaticity of the test light used).
5. An objective calibration procedure that can be applied to both types of optometer was employed in this study and is described herein.

RECOMMENDATION

The vernier optometer described in this report was implemented using optical bench and various hand-fabricated components. We believe that the design of the instrument is now sufficiently mature to warrant a permanent version with which to continue research on dark and empty-field myopia.

Acknowledgments

We wish to give special thanks to Dr. Jim Marsh of the University of West Florida for his assistance in the development of the objective calibration protocol reported here. Vernier and the laser-Badal optometers both require subjective responses and are not at all similar in design. This meant, that in the past, calibration involved a series of careful measurements, the judicious application of theory, and a great deal of faith.

We also wish to thank Dr. Robert Hennessy of Monterey Technologies, Inc., for the design of our initial vernier optometer and Ensign Donald Pagel for the data collection reported here.

INTRODUCTION

Much of the research on night myopia or dark focus and the other so-called anomalous myopias, such as empty field and instrument myopia, has been done with the laser-Badal optometer (1,2). This instrument held promise as a practical screening device as it was the first optometer used to measure dark focus in a large number of untrained subjects (3,4). To make measurements with this instrument, the subject is asked to judge when a speckle pattern ceases to move up or down. This speckle pattern is produced when coherent light from a laser is illuminating a rotating drum and will, theoretically, appear to move in a random fashion when the plane of focus of the laser light image coincides with the plane of the retina (5,6).

In our experience, the laser-Badal optometer has a number of shortcomings as a screening instrument. These have been discussed in depth elsewhere (7); in brief, we have found that the discrimination of speckle pattern movement is difficult for some subjects. In fact, about 15% of the subjects we tested were not able to perceive the speckle pattern at all when the stimulus was presented as a 500-ms flash. (The stimulus was presented as a flash to minimize possible artifacts arising from the surface contours of the rotating drum.) Even for the subjects who could perceive the speckle pattern, an experienced test administrator was needed, and testing time averaged 20 min.

The vernier optometer we constructed from Dr. Hennessy's design (Hennessy Optometry), on the other hand, is easy to use. The subject needs only to align two lighted lines, a "vernier" task. The image is always in focus because the design incorporates two pinholes, thus giving a very long depth of field. Head position is a critical factor. Results from off-center eye positions are discrepant from on-center measurements. Furthermore, since this version uses a broad-band white light source, chromatic aberrations from the lenses and pinholes are appreciable. These aberrations seemed to be a serious source of error. To test this hypothesis, we intentionally introduced a chromatic bias with red and blue filters. One extreme subject had a mean difference of 2.43 diopters (D) between the two conditions. The mean difference for all subjects tested (10 subjects, 30 trials each condition) was 0.838 D, with blue light indicating more myopia than red. This result is consistent with what would be expected from the known chromatic aberrations of the human lens. If, however, a broad-band stimulus is used in an optometer, the question of exactly which frequency is being used as a criterion must be asked.

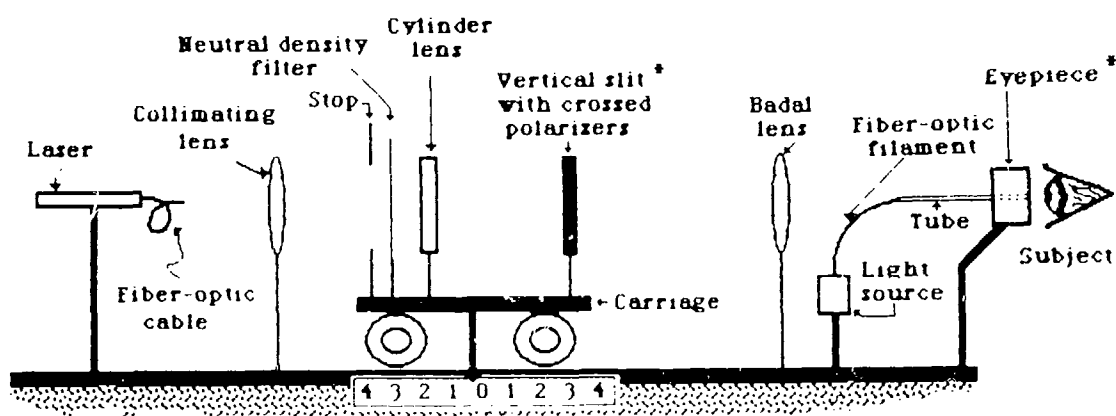
The new vernier optometer design described here (NAMRL Vernier Optometer) incorporated several modifications and improvements over our original implementation of the vernier principle. Monochromatic light was used to eliminate the effects of chromatic aberrations. The pinholes necessary to ensure a long depth of field were placed close to the eye, thus causing off-center eye positions to occlude the image. In this way, the effects of off-axis eye position on the optometer readings were minimized. As a further aid to maintaining proper eye position, a separate "bull's eye" pattern was presented superposed on the vernier junction. The vernier itself was oriented vertically, on the theory that vertical head

movements are more common than horizontal ones due to the influence of gravity. Movements along the long axis of the vernier image seemed to have no effect on the resultant setting.

To objectively calibrate the optometers, an "artificial eye" which consisted of a ground-glass "retina" placed at the exact focal length of a positive lens was constructed. This "artificial eye," focused at optical infinity, provided a zero point of reference for our instruments. Various dioptric "errors" were implemented by placing known lenses in front of the "eye" and observing the effect of the optometer image on the ground glass "retina." This procedure provided an objective method of observing optometer performance over a range of dioptric powers while remaining independent of the type of optometer used.

METHOD

THE NEW OPTOMETER



* See detail drawings

Figure 1 An accurate vernier optometer.

Figure 1 is a schematic drawing of the NAMRL vernier optometer. To facilitate comparison of the vernier optometer described here with a laser optometer using a helium-neon laser, the vernier optometer was also fitted with a helium-neon laser light source. By doing this, we temporarily avoided the issue of correcting for the chromaticity of the light source. The laser light source is indicated on the far left of Fig. 1. A short length of fiber-optic cable is the next element in the optical path. This cable makes an excellent beam expander. Next, a collimating lens is placed such that the light beam is again comprised of parallel rays, with a beam width of about one inch. A stop, neutral density filter, cylinder lens, and vertical slit with crossed polarizers are the next elements in the optical path. All of these elements are placed on a movable carriage, which the subject can adjust with a rack-and-pinion gear. The cylinder lens is placed at one focal length from the slit and oriented so that the slit is evenly illuminated. The movable carriage is equipped with a pointer that rides next to a stationary scale for reading carriage position. If the Badal lens is of 10 D, then the zero point of the instrument

will be with the slit 10-cm from the Badal lens (one focal length), and a movement of 1.0-cm will indicate a 1-D change in the subject's accommodation.



Figure 2. Detail of vertical slit as seen from direction of subject. A horizontal polarizer is over the top and a vertical polarizer is over the bottom of the slit.



Figure 3. Detail of eyepiece as seen by subject. The left viewing hole is covered by a vertical polarizer, and the right hole is covered by an horizontal polarizer. The center hole looks into the tube with fiber optic filament.

Figures 2 and 3 detail the slit and eyepiece, respectively. The pinholes in the eyepiece are approximately one focal length from the Badal lens. The optometer is an application of the Scheiner principle (8) and works by separating the image of the slit into two light bundles that are physically displaced as they enter the subject's eye. In order for the vernier image to be aligned on the subject's retina, the optics of the optometer and the subject's eye must be such that image divergence due to refraction in the various elements is exactly canceled. That is, the image is in focus on the retina. In the case of an optometer, the image should always appear to be in focus so that mechanisms within the subject's visual system that drive accommodation are not stimulated. This seemingly contradictory state of affairs is accomplished by polarizing filters, which separate the image into two independent light paths, and by pinholes, which achieve a very long depth of focus as described below. Figures 1 through 3 show the physical arrangement.

The slit is covered by two polarizing filters, exactly crossed relative to one another and arranged such that light exiting the slit is polarized in one direction from the top half of the slit and 90° away from the bottom half. The image of the slit, therefore, is comprised of light with two orientations when it reaches the eyepiece where it must again pass through crossed polarizers covering the exit pinholes. In this manner, light from, for example, the top half of the slit is directed through the left pinhole and blocked from the right. At the same time, light from the bottom half of the slit is directed through the right pinhole and blocked from the left.

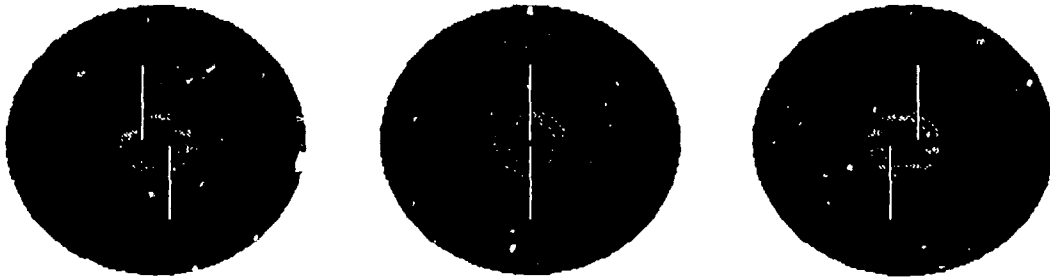


Figure 4. The subject's view as the optometer is adjusted.

When the optometer is used, the subject sees an image similar to that shown in Fig. 4. The annular image is caused by light reflecting from the inside of a tube attached to the center pinhole and illuminated with a fiber-optic filament from a separate light source. In the apparatus shown here, a white light was used to produce this image. This annular image is provided to aid the subject in keeping an eye aligned with the apparatus. Depending on the state of the subject's accommodation, the image of the slit will be aligned or not, as shown in Fig. 4. If it is not aligned, then the ray bundles from the two outer pinholes are either being refracted too little or too much, causing them to meet or cross either behind or in front of the retina. If the ray bundles cross in front of the retina, then the accommodative state of the eye is too strong for the proper focus of the stimulus on the retina. That is, the subject is myopic. Movement of the slit toward the Badal lens will cause the exit rays from the Badal lens to diverge, thus compensating for the myopic state of the subject's eye, and will bring the two halves of the slit image into alignment on the retina. Thus, the position of the slit relative to the Badal lens is a direct function of the subject's accommodative state when the subject brings the vernier image into alignment. Movement of the slit toward the Badal lens is required to compensate for myopia, while movement away from the Badal lens compensates for hyperopia.

CALIBRATION

Proper application of optical principles and careful measurement will yield a good instrument calibration. On the other hand, accurate measurement to the principal planes of lenses is not inherently easy to do, and lenses are sometimes shipped with powers that do not correlate well with the labels on the boxes. When an entire instrument is at issue, the opportunity for cumulative error increases considerably. For these reasons, we sought a direct means of effecting a calibration that had validity relative to the purpose of the instrument and that was essentially independent of the instrument.

The purpose of an optometer, such as the one described here, is to measure the refractive power of a lens focusing an image on a screen (the retina). The zero dioptric power point of the human eye is that condition where objects at infinity are exactly focused on the retina, that is, when

the retina is exactly one focal length from the lens of the eye. This condition can be imitated with a simple positive lens and a ground glass screen placed at one focal length. If such an "artificial eye" is constructed and placed such that the vernier image from the optometer is aligned on the screen, or the speckle pattern from a laser optometer moves randomly, then the optometer is, by definition, at zero.

The construction of an "artificial eye" focused at infinity is simple. We used an achromatic positive lens with a focal length of approximately 10 cm and a ground glass screen in a rigid metal housing. The distance of the screen from the lens was adjusted using an auto-collimation technique. That is, a piece of silvered paper with a pinhole was affixed to the ground glass screen and illuminated with a strong light source. The image of the pinhole was, therefore, projected from the lens. A flat mirror was then held in front of the lens, and the image reflected back through the lens to the ground glass screen on an area not covered by the paper. The screen distance was then adjusted until this reflected image was exactly focused on the screen. The only condition where an image is in focus at the same distance as the source of the image, after being reflected by a plane mirror, is when the screen is exactly one focal length from the lens. If this distance is maintained, then the "artificial eye" is focused at infinity.

Both the vernier and the laser-Badal optometers were calibrated using this "artificial eye." The first step was to use the "eye" as constructed to find the zero point of the instrument. This was done by placing the "eye" in the normal viewing position of the subject and observing the image from the optometer on the ground-glass screen. The point where the vernier aligned, or the speckle pattern motion was random, was then taken as the zero point. Next, a series of trial lenses in 1-D steps was placed in front of the "artificial eye" and the optometer adjusted until the vernier again aligned or the speckle-pattern motion again appeared random. A 1-D lens placed in front of the "artificial eye" was taken as the equivalent of a 1-D change in accommodation, and the distance the optometer was adjusted to compensate for each diopter change was used as the calibration slope of the instrument.

CHROMATIC EFFECTS

Blue light, being more energetic, is refracted more than red light in any but an achromatic lens. The human lens is no exception. Presumably, then, any optometer based on the Scheiner principle must take this phenomenon into account. An optometer utilizing a blue light source will diverge the light entering the pupil more than red light to bring the image into alignment on the retina. In other words, with all things being equal, a subject will appear to be more myopic with a blue light source than a red one. The data reported above comparing the laser and vernier optometers have not been corrected for this chromaticity effect. By convention, the "zero" point for studies in accommodation is usually taken as monochromatic yellow light (9). For future implementations of the optometer design presented here, we propose using an essentially monochromatic light-emitting diode with a peak emissivity at 583-nm as the light source (for example HLMP-3850). This diode would be built into the carriage structure shown in Fig. 1, thus eliminating the fiber-optic cable and the need for chromaticity correction.

Generally, a correction of 0.33 D of myopia is added to the results of an optometer using 632.8-nm laser light. Using the optometer described here, modified to have a white light source and either red or blue gelatin filters, we recorded a mean difference of 0.838 D between the two conditions (SD = 0.6624, 10 subjects, 30 settings per subject in each condition an interleaved set of trials). These data suggest that the correction generally used is adequate. The use of a monochromatic diode source will eliminate the need for this correction.

A DIRECT COMPARISON OF THE VERNIER AND LASER OPTOMETERS

The vernier optometer described here was compared with a laser-Badal optometer to verify the contention that they measure the same thing. The results of this verification study were successful. Twenty subjects participated in the study. They were all aviation candidates awaiting orders to U.S. Navy flight school and had excellent vision. The subjects were all tested at a mesopic ambient light level. The comparison was done with an interleaved design. Subjects were asked to complete 10 settings of the vernier optometer, then 10 settings of the laser-Badal optometer, then back to the vernier optometer, and so on until 30 settings on each were completed. The mean of all 600 vernier settings was 1.131 D of myopia (SD = 0.26 D) and the mean of all 600 laser-Badal settings was 1.036 D of myopia (SD = 0.32 D). There is a difference of only 0.095 D (not statistically significant). Both optometers used Helium-Neon lasers as light sources. The light from the lasers is at a frequency of 632.8-nm and must be corrected for chromaticity error (add 0.33 D of myopia) if comparing these data to other data in the literature.

DISCUSSION

We conclude that the optometer design presented here is valid. It is also relatively easy to build and use. Furthermore, the standard deviation of data taken from the vernier optometer is smaller than the equivalent standard deviation taken from the laser-Badal optometer. This finding compares nicely with the ease of use of the instrument, and is probably a direct result of the fact that it is "user friendly."

RECOMMENDATION

In a future, more permanent, implementation of the optometer described here, a monochromatic yellow light-emitting diode should be used for the light source and should be mounted directly on the movable carriage shown in Fig. 1. This design refinement eliminates the need for a laser, the fiber-optic bundle, and a chromaticity correction. The light source for the annular surround should be from a red or green light-emitting diode. Both of these light sources should be switched on with an electronic timer so that brief as well as continuous presentations are possible. A cube-type beam-splitter should be affixed to the eyepiece. This beam-splitter would allow the subject to either look directly into the instrument or through the beam splitter at a distant target and see the vernier target superposed on the distal image.

An optometer such as the one described here is useful for research in the area of "dark focus" or "empty field myopia" because it can provide a measure of the refractive state of an individual while minimally stimulating accommodation.

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