

USAARL Report No. 94-23



**Focus Adjustment Effects on Visual Acuity
and Oculomotor Balance
with Aviator Night Vision Displays
(Reprint)**

By

John C. Kotulak

and

Stephen E. Morse

Aircrew Health and Protection Division

April 1994

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**United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577**

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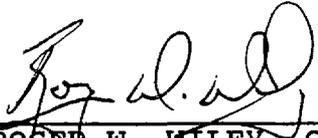
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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 94-23		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory		6b. OFFICE SYMBOL (If applicable) SGRD-UAS-VS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research, Development, Acquisition and Logistics Command(Provisional)		
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577		7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO. 0602787A	PROJECT NO. 3M162 787879	TASK NO. BG	WORK UNIT ACCESSION NO. 174
11. TITLE (Include Security Classification) (U) Focus Adjustment Effects on Visual Acuity and Oculomotor Balance with Aviator Vision Displays (Reprint)					
12. PERSONAL AUTHOR(S) John C. Kotulak and Stephen E. Morse					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) 1994 April		15. PAGE COUNT 5
16. SUPPLEMENTARY NOTATION Printed in <u>Aviation, Space, and Environmental Medicine</u> , April 1994, Vol. 65, pages 348-352					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Night vision displays, focus adjustment, visual acuity, oculomotor balance		
20	06				
23	02				
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Sixteen U.S. Army aviators, who were given training on focus adjustment technique with aviator night vision goggles (NVG), showed an improvement in visual acuity with focus adjustment compared to a fixed infinity focus control. The long-term effect of focus adjustment on vision was not measured; however, adjustment accuracy was found to be generally within acceptable limits based on computer modeling and available physiologic data. Fixed focus eyepieces that are set to a low minus power may partially compensate for instrument myopia, but they may not optimize visual acuity to the extent that adjustable focus eyepieces do. Eyepiece adjustment proficiency with present night vision devices can be improved through training that emphasizes focusing to the least possible minus dioptric power. Future night vision displays can minimize focus misadjustment by providing a tactile zero marking, a limited dioptric adjustment range, and a focusing knob capable of finer adjustment than is available with current NVGs.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center		22b. TELEPHONE (Include Area Code) (205) 255-6907		22c. OFFICE SYMBOL SGRD-UAX-SI	

TECHNICAL NOTE

Focus Adjustment Effects on Visual Acuity and Oculomotor Balance with Aviator Night Vision Displays

JOHN C. KOTULAK, O.D., M.S., and STEPHEN E. MORSE, O.D., Ph.D.

KOTULAK JC, MORSE SE. *Focus adjustment effects on visual acuity and oculomotor balance with aviator night vision displays.* *Aviat. Space Environ. Med.* 1994; 65:348-52.

Sixteen U.S. Army aviators, who were given training on focus adjustment technique with aviator night vision goggles (NVG), showed an improvement in visual acuity with focus adjustment compared to a fixed infinity focus control. The long-term effect of focus adjustment on vision was not measured; however, adjustment accuracy was found to be generally within acceptable limits based on computer modeling and available physiologic data. Fixed focus eyepieces that are set to a low minus power may partially compensate for instrument myopia, but they may not optimize visual acuity to the extent that adjustable focus eyepieces do. Eyepiece adjustment proficiency with present night vision devices can be improved through training that emphasizes focusing to the least possible minus dioptic power. Future night vision displays can minimize focus misadjustment by providing a tactile zero marking, a limited dioptic adjustment range, and a focusing knob capable of finer adjustment than is available with current NVG's.

AN OPTICAL INSTRUMENT that is equipped with an adjustable focus eyepiece typically is focused as though the user of the instrument were myopic, regardless of the user's true refractive status. This phenomenon has given rise to the notion that instrument viewing induces a transient myopic state; hence the term, "instrument myopia." Instrument myopia has been observed with telescopes (16), microscopes (14), binoculars (4), helmet mounted displays (1), and night vision goggles (NVG) (8). Its presumed mechanism is excessive accommodation (8,14,17).

Although adjustable focus eyepieces have been in use for a long time, little is known about their efficacy in improving vision. We do know that optimum visual acu-

ity for an emmetrope (an individual without refractive error) is achieved when the instrument eyepiece is set to a low minus power rather than to infinity (zero power) or to a high minus power (12,13). This suggests that an adjustable focus eyepiece could serve a useful role in compensating for instrument myopia and improving vision, provided that the user of the instrument has the necessary skill and training to focus it properly. On the other hand, the misadjustment of eyepieces by untrained or unskilled users can lead to visual problems (5). This paper will address three questions of aeromedical interest regarding the focus of eyepieces on aviator night vision displays:

1. How effectively do aviators make eyepiece adjustments with current equipment?
2. What would be the effect of using fixed-focus eyepieces in future night vision displays?
3. What can be done to make aviators more proficient with focus adjustment with present and future displays?

How Effectively Do Aviators Focus Eyepieces?

Effect of Adjustment on Visual Acuity

One way to gauge the effectiveness of aviator eyepiece adjustment is to measure visual acuity before and after adjustment, given that before adjustment the eyepiece is focused at infinity. Such a comparison was done with 16 emmetropic Army aviators using generation III binocular NVG's (6). Each subject received refresher training on eyepiece adjustment technique prior to data collection. Fig. 1, which is modified from Kotulak and Morse (6), shows that visual acuity was better when the focus was adjusted by the user than when the focus was fixed at infinity. The difference in acuity between fixed and adjustable focus was statistically significant for all target conditions (Table I).

Fig. 1 also plots data from another study (10) in which acuity was measured with generation II NVG's, which

From the Visual Sciences Branch, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL.

This manuscript was received for review in April 1993. It was revised and accepted for publication in June 1993.

Address reprint requests to: LTC John C. Kotulak, Research Optometrist, U.S. Army Aeromedical Research Laboratory, P.O. Box 620577, Fort Rucker, AL 36362-0577.

EFFECTS OF FOCUS ADJUSTMENT—KOTULAK & MORSE

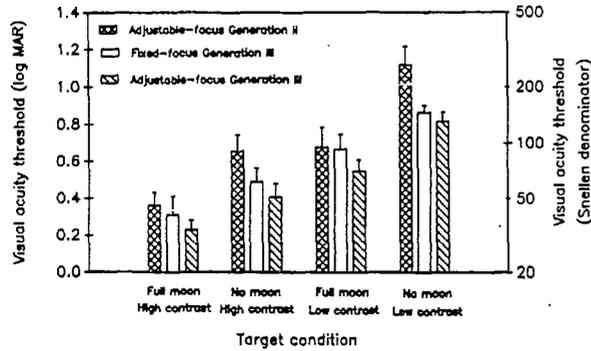


Fig. 1. Visual acuity through fixed and adjustable focus third generation and adjustable focus second generation night vision goggles as a function of target contrast and night sky condition. The acuity thresholds are expressed as both the log of the minimum angle of resolution (log MAR) and in Snellen notation. The error bars represent 1 SD.

are markedly inferior to those of the current generation III with respect to resolution. Despite this, fixed focus generation III performance was no better than adjustable focus generation II performance for half the conditions tested. Thus, without an adjustable focus eyepiece, the leap in technology between generations of NVG's is not fully realized. Table II gives the results of the statistical analysis.

Effect of Adjustment on Oculomotor Balance

The data in Fig. 1, which were obtained immediately after the eyepieces were adjusted, do not represent whether or not visual acuity is likely to degrade over time. Degradation could occur if the eyepieces were focused to excessive minus power, which for a binocular display can take on two forms: 1) both eyepieces could be "overminused" by roughly equal amounts, which creates a mismatch between accommodation and convergence (5); and 2) one eyepiece could be overminused more than the other, which creates unequal accommodative demands between the two eyes (8).

Mismatch between accommodation and convergence: The first problem, the mismatch between accommodation and convergence, occurs if the eyepieces are overminused to the extent that they cause the eyes to accommodate (focus) to a point which is sufficiently different from the point to which they are converged (aimed). The term "relative accommodation" is used to describe the degree to which accommodation is mismatched with convergence under these circumstances.

TABLE I. MULTIPLE COMPARISON TESTING FOR DIFFERENCES IN VISUAL ACUITY BETWEEN FIXED AND ADJUSTABLE FOCUS EYEPIECES.

Night Sky Condition	Target Contrast	
	High	Low
Full Moon	p = 0.01	p = 0.003
No Moon	p = 0.008	p = 0.003

The p-values were adjusted for alpha inflation.

TABLE II. MULTIPLE COMPARISON TESTING FOR DIFFERENCES IN VISUAL ACUITY BETWEEN FIXED FOCUS GENERATION III AND ADJUSTABLE FOCUS GENERATION III NVG.

Night Sky Condition	Target Contrast	
	High	Low
Full Moon	p = 0.3	p = 1.0
No Moon	p = 0.0004	p = 0.0004

The p-values were adjusted for alpha inflation.

The accommodative system, which maintains clear vision by controlling the refractive power of the lens of the eye, and the convergence system, which maintains single vision by controlling the alignment of the lines of sight of the eyes, can be dissociated only to a limited degree, beyond which either blur or double vision results. Jones (5) has proposed, based on a computer simulation, that the limit of dissociation between accommodation and convergence is ± 2 units, when accommodation is expressed in diopters and convergence is expressed in meter angles (numerically equivalent units since both are reciprocals of distance in meters). However, Jones pointed out that comfortable vision is probably not possible at the upper limit of the dissociation range, and has suggested that ± 1 unit is a more practical limit based on clinical considerations.

The focus adjustments that generated the improvement in acuity shown in Fig. 1 stimulated on average only 0.55 diopters of accommodation (7,8,9). Convergence during this experiment was 0.17 meter angles because the test distance was 5.8 m ($1/5.8 = 0.17$). Therefore, the mismatch between accommodation and convergence was only 0.38 units (0.55 diopters—0.17 meter angles), which is well within the tolerance of 1 unit proposed by Jones (5). Fig. 2 shows that the mismatch between accommodation and vergence (relative accommodation) remains well within the limits proposed by Jones over the entire range of operationally significant target distances. This, when combined with the data in Fig. 1, suggests that properly trained aviators

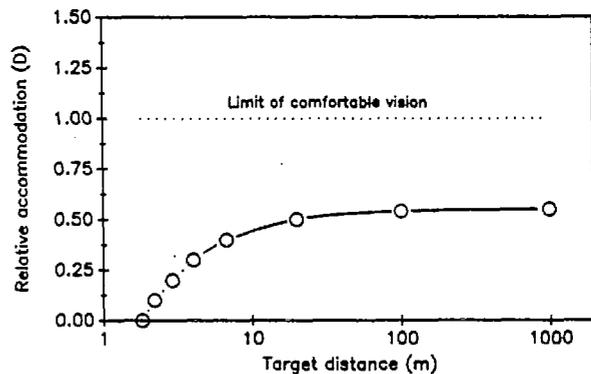


Fig. 2. Mismatch between accommodation and convergence after user focus adjustments as a function of target distance. Relative accommodation is the amount of accommodation that is in excess of the amount of convergence. The limit of comfortable vision is from Jones (5).

are capable of adjusting eyepieces in a manner that improves acuity and that does not disturb the relationship between accommodation and convergence.

Unequal accommodative demands: Another way in which overminusing can cause problems with binocular instruments is by creating unequal accommodative demands between the two eyes through the inappropriate focusing of the two eyepieces to different powers. When this occurs, the accommodative response is usually governed by only one of the eyepiece settings, rather than by a compromise between the two (6). As a result, the retinal image is in focus in one eye and out of focus in the other.

If the between-eye discrepancy in retinal image clarity is too great, then the eye with the greater amount of defocus is suppressed; i.e., visual perception in that eye is inhibited by the cortex (15). However, suppression does not occur when the focus difference between the two eyes is less than about 0.5 diopters (15). Also, stereopsis is not compromised until the focus difference exceeds about 1 diopter (3). The between-eye differences in focus adjustment for the generation III subgroup of subjects from Fig. 1 is given in Fig. 3, as well as the thresholds for suppression of large and small targets from Simpson (15). Fig. 3 demonstrates that the mean between-eye focus discrepancy for all target conditions falls below the threshold for suppression of small targets. However, the variability of the focus discrepancies is large enough to suggest that some individuals may suffer from monocular suppression of small targets.

In summary, the data suggest that aviators focus their eyepieces on binocular displays well enough not to interfere with the balance between accommodation and convergence, but not well enough to be free from all monocular suppression.

What Would Be the Effect of Using Fixed Focus Eyepieces?

Future Aviator Night Vision Displays

Present U.S. Army aviator night vision displays, such as NVG's and the Apache helicopter helmet-mounted

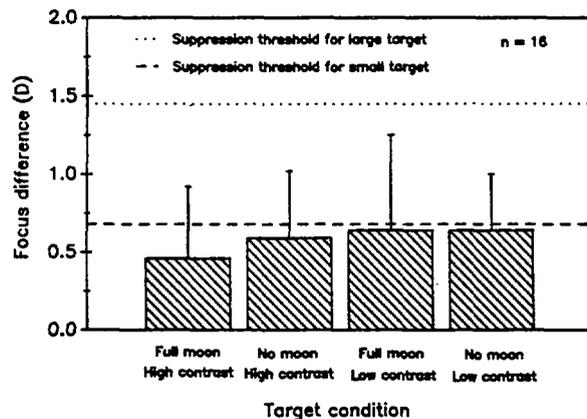


Fig. 3. Between-eye difference in focus as a function of target condition. Suppression thresholds are from Simpson (14). Error bars represent 1 SD.

display, have adjustable focus eyepieces. However, the expected increase in complexity of future displays will make the incorporation of adjustable focus eyepieces difficult. Fixed focus eyepieces will eliminate user misadjustment as a source of visual problems; however, they suffer from weaknesses that adjustable focus eyepieces do not.

Non-Infinity Fixed Focus Eyepieces

The effects of fixed infinity focus eyepieces on visual acuity have been explained already in Fig. 1 and Tables I and II. However, fixed focus eyepieces may be set to a dioptric value other than infinity; e.g., to a low minus power (13). This would provide some compensation for instrument myopia without the risk of eyepiece misadjustment. However, because the amount of instrument accommodation varies greatly among subjects (6) (Fig. 4), non-infinity fixed focus eyepieces may not optimize vision to the extent that adjustable focus eyepieces do, especially when the latter are in the hands of skillful users.

Hyperstereopsis in Future Displays

Current aviator NVG's have the image intensifier sensors mounted directly in front of the eyes. However, future helmet-mounted displays may have these sensors mounted on the sides of the helmet, which will cause the spacing between the sensors to exceed the normal interocular separation. When this happens, a condition known as hyperstereopsis results. In hyperstereopsis, apparent depth relationships are exaggerated, and the eyes converge to a point that is closer than the point to which they accommodate (2).

Fig. 5 demonstrates this effect. The y-axis, which is labelled "relative convergence," is the amount of convergence that is in excess of the amount of accommodation, assuming that the amount of accommodation is zero. It can be seen that relative convergence varies directly with the degree of interocular separation and inversely with target distance. The dotted line defines the limit of comfortable vision, which comes from Jones (5) and was discussed earlier. Relative convergence val-

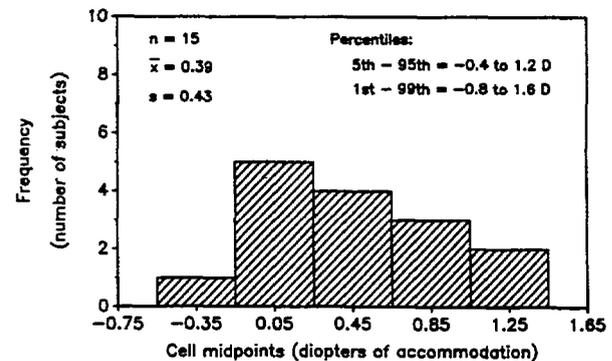


Fig. 4. Frequency distribution of instrument accommodation for fixed infinity focus night vision goggles. Negative values on the abscissa indicate hyperopic responses. Percentiles are given for instrument accommodation. To determine percentiles for eyepiece adjustment range, the signs must be reversed.

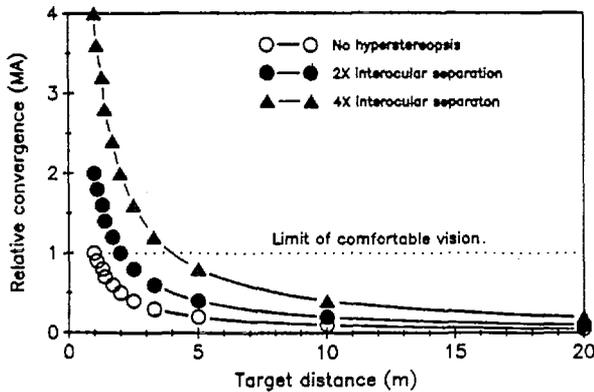


Fig. 5. Mismatch between convergence and accommodation for binocular displays with and without hyperstereopsis as a function of target distance. Relative convergence in meter angles (MA) is the amount of convergence that is in excess of accommodation, given that the amount of accommodation is zero. The limit of comfortable vision is from Jones (5).

ues above the line are likely to result in symptoms. Fig. 5 demonstrates that hyperstereopsis disturbs the balance between accommodation and convergence, but predominantly at distances less than 5 m. However, operationally significant target distances can be as little as 2 m for helicopter aviators; e.g., clearance of obstacles during nap-of-the-earth flight.

It is significant that the mismatch between accommodation and convergence that is created by hyperstereopsis is opposite to the one caused by eyepiece misadjustments. Eyepiece misadjustments typically increase accommodation relative to convergence, while in hyperstereopsis, convergence is increased relative to accommodation. A paradoxical result is that in displays with hyperstereopsis, focus misadjustments could actually reduce the mismatch between accommodation and convergence (because they typically stimulate accommodation), and thus help restore the normal relationship between the two. Conversely, fixed infinity focus eyepieces, which may be used with future helmet-mounted displays, would promote a greater mismatch between accommodation and convergence than adjustable focus eyepieces if the display produces hyperstereopsis.

What Can Be Done to Improve Focus Adjustment Proficiency?

Training

Behar et al. (1), who studied focus adjustment with a monocular helmet-mounted display, concluded that overminusing could be reduced substantially with proper training. Behar and his colleagues found that the best results were obtained when the adjustment knob initially was rotated counterclockwise into plus dioptric power so as to blur the image, then rotated clockwise toward minus power, and finally stopped at the first point at which the image cleared.

An additional consideration with binocular instruments, such as NVG's, is what to do about the left eye when the right eyepiece is being adjusted, and vice versa. Two schools of thought have emerged, one in

which the opposite eye is occluded, and the other in which the opposite eye is slightly blurred. If one eye is occluded, the focusing technique is referred to as "monocular," and if one eye is blurred, the technique is called "binocular." Although the U.S. Army teaches both techniques, we found that 15 out of 16 aviators tested used the monocular method. The results reported earlier in this paper revealed improved visual acuity with focusing (when the monocular method was used) compared to the fixed infinity focus control, with oculomotor balance remaining mostly within acceptable limits. However, the binocular technique holds the potential for further improvement in visual performance because it facilitates the control of instrument accommodation through the mediation of "vergence accommodation." When the lines of sight of the eyes are parallel, as with NVG's, innervation from the vergence oculomotor system tends to reduce the amount of the aggregate accommodative response (11).

Engineering Controls

Behar et al. (1) also recommended that a detent be added to the focusing knob to help locate the infinity position. A tactile zero marking, such as a detent, would be especially valuable in night vision displays, which are often focused when it is too dark to read the eyepiece scale. However, for the detent to be useful, the manufacturing tolerances would have to be small (e.g., ± 0.125 diopters). In addition, misadjustments could be controlled if the eyepiece adjustment range were limited to the physiologic realm, which is probably from +1 to -2 diopters (Fig. 4). NVG's and the Apache helmet-mounted display have considerably larger ranges. Finally, a diopter adjustment that is too fine or too coarse increases the risk of inaccurate focus. The entire range of 3 diopters should be accommodated in approximately one turn of the adjustment knob.

Recommendations for Improving Adjustment Proficiency

Present Night Vision Displays

1. Training on eyepiece adjustment should emphasize reaching a most plus endpoint.
2. Research is needed to establish the efficacy of the binocular eyepiece adjustment technique. If the binocular technique is found to be superior to the monocular technique, the binocular method should be given training emphasis.

Future Night Vision Displays

1. Adjustable eyepieces should have a reliable scale, with zero diopters identified by a tactile marking.
2. The dioptric adjustment range should be limited to approximately +1 to -2 diopters.
3. The adjustment knob should be considerably less coarse than that of existing NVG's.

ACKNOWLEDGMENTS

The protocols for the experiments described in this paper were approved by the Human Use Committee of the U.S. Army Aeromedical Research Laboratory. The subjects were advised of their right to withdraw from the experiment at any time, and gave their informed

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consent. The views, opinions, and/or findings contained in this paper are those of the authors, and should not be construed as an official Department of the Army position, unless so designated by other official documentation.

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