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Attenuating the Luminous Output of the AN/PVS-5A Night Vision Goggles and Its Effects on Visual Acuity

By

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and

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September 1989

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

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Aviators in combat may be subjected to a variety of noxious light stimuli. Filters and other eye protective devices may be used to counter these threats. At night, filters may be used in conjunction with image intensification devices (e.g., night vision goggles) to provide useful low-light vision as well as protection from deleterious light sources (e.g., lasers, pyrotechnics, nuclear fireballs, etc.). Technologies may be combined in a single, integrated head gear unit. The present study was performed in order to consider the effects on visual acuity after reducing night vision goggle luminous output from 0-99 percent. A range of target contrasts and ambient illumination levels was investigated. AN/PVS-5A goggles were selected based upon their compatibility with current phosphor display technology and their current ubiquity within aviation units. Visual acuity was assayed behaviorally because of its critical importance in flying performance. The

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results of the study provide normative acuity data with goggles alone and document the effects on goggle visual acuity with reduced goggle luminances as might be produced by protective materials placed between the goggles and the eyes. Keywords: light filters, human factors engineering; night vision devices, (KT)

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Appreciation is expressed to Sergeants Jim Bohling and Vincent Reynoso for providing expert technical assistance in the collection of data and to our volunteer subjects who generously provided us with their most valuable workday commodity -- their time.

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Introduction

Among the threats confronting the Army aviator in combat are those that will challenge his visual integrity and impair his visual performance. Pyrotechnics, high-intensity searchlights, electronic strobes, and fireballs produced by tactical nuclear weapons all represent battlefield sources of noxious light energy with the potential to degrade visual function. A more recent threat is that of exposure to directed energy from ground- or air-based laser platforms. Such systems could be used not only to designate aircraft, but, at appropriate powers and wavelengths, to flashblind aircrews and produce ocular injury.

At present, the Army is developing an integrated flight helmet (Head Gear Unit-56/P [HGU-56/P]) that will provide visual prophylaxis against debilitating sources of light most likely to be encountered on the battlefield. One preliminary design incorporates a visor-goggle arrangement that will attenuate the exposure to both laser energy and nuclear flash. Unfortunately, along with their intended objective of providing ocular protection, protective materials placed in front of the eyes will have the additional effect of reducing the light available for seeing. (Even optical quality clear glass loses 4 percent of the incoming light per surface.) Under optimal (i.e., bright light) viewing conditions, the reduction of light due to protective devices should have but minimal effects on visual function. However, any additional loss of available light could aggravate the already limited visual capabilities of pilots at night.

One proposal offered by Army planners prescribes that pilots use image intensification (I^2) devices (e.g., night vision goggles [NVGs]) in conjunction with the ocular protective materials to augment their nighttime viewing capabilities. While NVGs inherently compromise the quality of vision (reduced acuity, depth perception, visual field, and color vision), the operational capabilities they provide far outweigh the visual shortcomings associated with their use. However, decreasing the NVG's output brightness with filters or other protective materials could further degrade image quality and, in so doing, further impair visual function and perception. Indeed, reducing photopic acuity further could effectively hinder safe flight.

The present study was designed to examine visual acuity with AN/PVS-5 night vision goggles after reducing normal output luminance by as much as 99 percent. Data were collected in the laboratory over a range of low ambient illumination conditions and target-background contrasts. The work was conducted in conjunction with a tasking by the Directorate of Combat Developments, U.S. Army Aviation Center, Fort Rucker, Alabama, to evaluate the effects of nuclear flashblindness material on visual acuity with NVGs (Appendix A). The data presented here extend those reported in the study performed in response to that tasking (Levine and Rash, 1989).

Methods

<u>Subjects</u>: Eight volunteers, seven military and one civilian, aged from 20-37, participated in the study. All participants had 20/20 or better uncorrected Snellen visual acuity as measured under standard, clinical test conditions. Six of the eight participants had over 50 combined hours of NVG experience as subjects in prior studies and were highly familiar with the experimental procedures. The remaining two subjects were NVG-inexperienced and experimentally naive; both were permitted sufficient opportunity to practice and adapt to viewing through the goggles.

<u>Apparatus</u>: Subjects sat in a darkened room 20 feet from a 12" monochrome CRT upon which individual, computer-generated, Snellen letters "E" were presented as targets. Subjects viewed the CRT through a single pair of AN/PVS-5A NVGs mounted on a table in front of them (Figure 1). Goggle height and interpupillary distance were adjusted by the experimenter for each subject. Goggle batteries were changed after every 10 hours of use.

<u>Viewing conditions</u>:

Background CRT luminance - Three background CRT luminances were chosen to correspond to the ambient light levels associated with twilight (1/2 hour past sunset), full moon, and starlight (clear, moonless night; RCA Electro-Optics Handbook, 1974). Light levels were simulated by using large sheets of neutral density filter material placed over the screen to achieve the required levels of "ambient" illumination. CRT brightnesses were confirmed with a Pritchard 1980-A spectrophometer*. The monitor served as the only source of light in the room.

Target/background contrast level - Three contrast ratios -- 90, 30, and 3 percent -- were selected to represent conditions

* See Appendix D

Figure 1. Subject's viewing station with mounted AN-PVS-5A night vision goggles and hand-held joystick.

of high, moderate and low target/background contrast. Following Michelson (1927), contrast was defined as:

$$\frac{\text{background luminance - target luminance}}{\text{background luminance + target luminance.}}$$

The letters always appeared darker than their surrounds (negative contrast; Figure 2).

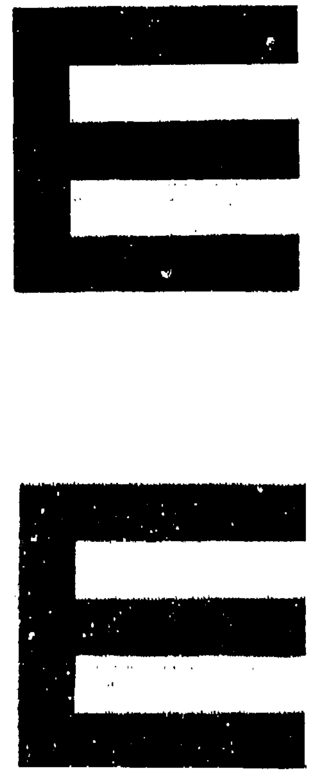

Figure 2. Snellen "E"s of high (top), medium (middle), and low (bottom) contrast.

Goggle luminances - The luminous output of the goggles was adjusted by a series of Kodak Wratten neutral density filters* that were trimmed, placed in specially constructed rings, and fitted onto the oculars of the goggles (Figure 3). Optical densities and corresponding light transmittances (in parentheses) for each of the filters were as follows: 0.30 (50 percent), 0.50 (30 percent), 1.0 (10 percent), 1.5 (3 percent), and 2.0 (1 percent). In addition, a baseline no filter condition (100 percent transmission) was included in which only the empty filter rings were used. The presentation order of each of the filter conditions was determined according to a quasi-random schedule (see below).

Procedures: Subjects were briefed on their required tasks and permitted 5-10 minutes to adapt to their darkened surroundings. They then focused the NVGs while viewing sample targets on the monitor.

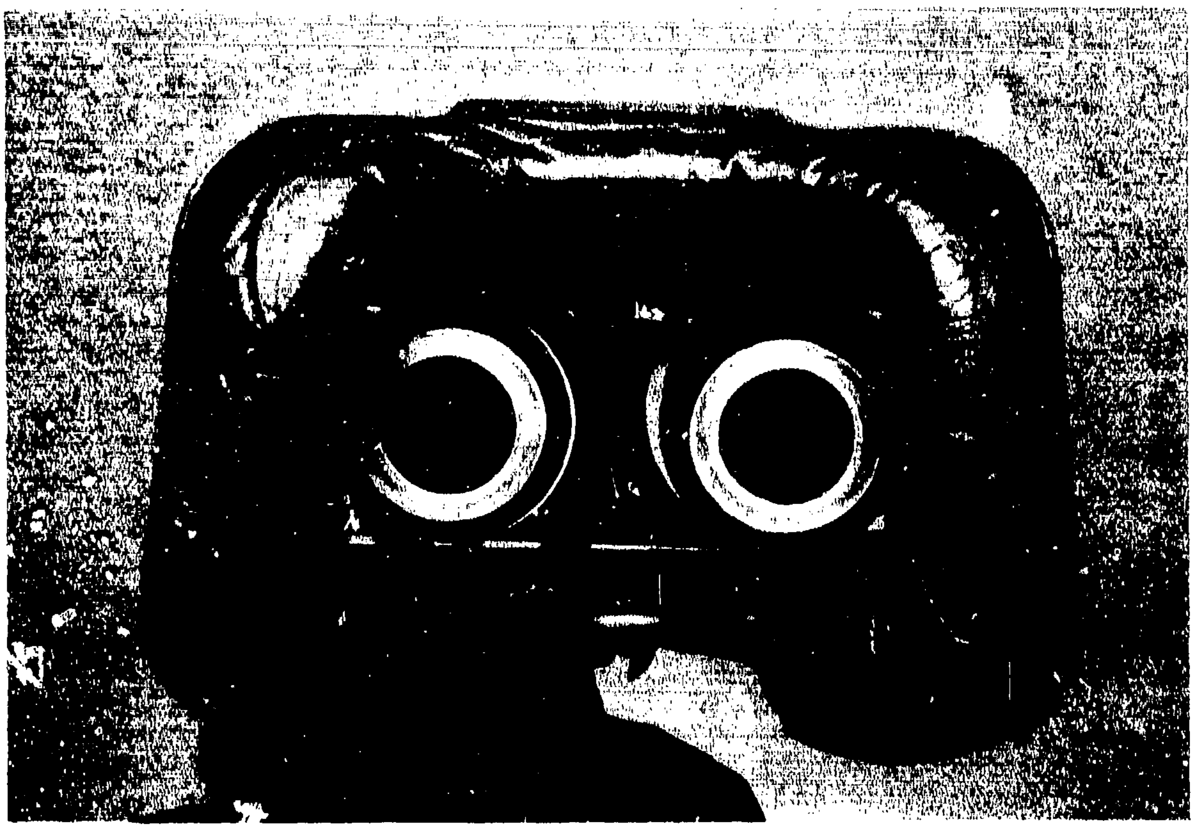

Figure 3. Night vision goggles with filters mounted onto the oculars.

During testing, the "E"s were displayed for 1 second on the CRT in one of the four cardinal orientations. The subjects indicated the orientation of the "E" with an appropriate movement of a hand-held joystick (a four-alternative forced-choice procedure). The orientation of the "E" was varied randomly under computer control while the size of the "E" and its rate of presentation (about once every 3 seconds) were controlled by an operator in an adjacent room. Letter sizes ranged, in terms of Snellen notation, from 20/10 to 20/400 (or, in terms of minimum angle of resolution, from 0.5 to 20.0 minutes of arc).

Threshold acuities were determined using the psychophysical method described by Wetherill and Levitt (1965). This technique employs a bidirectional method-of-limits to capture any one of several possible detection thresholds. A paradigm was selected to determine the 70 percent acuity threshold and modified to incorporate the four-alternative forced-choice procedure described above. The 70 percent threshold level was chosen in order to control for the effects of guessing and to provide a measure comparable to earlier work from this laboratory.

No penalties were imposed upon the subject for an incorrect or nonresponse and no performance feedback was provided. For the most difficult viewing conditions (e.g., moonlight, low contrast targets), subjects often could neither detect trial onset nor correctly identify the orientation of the largest (20/400) letter. To assist detection, subjects were cued with a verbal "ready" signal just before the start of these more "difficult" trials. (Other than providing a general orienting response, post hoc analysis indicated that this procedure had no practical consequences on the subject's performance. On "no response" trials, an acuity value of 20/600 was assigned arbitrarily and used in the calculation of the subject's threshold.)

<u>Experimental design and data analysis.</u> The study was conceived as a 3 (brightness: twilight, moonlight, and starlight) X 3 (contrast: high, moderate, and low) X 6 (percent goggle light transmission: 1, 3, 10, 30, 50, and 100) within-subjects design with repeated measures on all factors. Acuity, expressed in terms of the average minimum angle of resolution (MAR), served as the dependent variable. All 54 possible viewing conditions were presented randomly and exhaustively once to each subject. Data collection was accompanied over five sessions with each experimental session lasting about 1 hour.

Because NVGs deliver optimal performance (i.e., maximal brightness and peak acuity) over a limited range of ambient lighting and target conditions (clear, moonlit night, and high contrast targets), statistical analyses based upon a treatment effects model could be confounded by system limitations (producing both "ceiling" and "floor" effects). Therefore, the data are presented descriptively in order to demonstrate and clarify the functional relationships among the various levels of goggle output and their subsequent effects on visual acuity for targets of varying contrast. In addition to illustrating the effects of filters, the results also present baseline acuity data for the NVGs alone.

Results

Acuity with NVGs alone: Table 1 presents acuities with NVGs alone ("no filter" condition) at each level of brightness and contrast. Group means and ranges are shown for each viewing condition. Acuity is represented in terms of both the minimum angle of resolution and its approximate Snellen equivalent. These data were extracted from the complete data set and are presented here to both document and provide an estimate of "best case" NVG acuity under each of the conditions tested. (Means and standard deviations also are shown graphically in Appendix B.)

As shown in Table 1, mean acuities ranged from 20/40 under the most favorable viewing conditions (twilight and high contrast) to 20/400 under the poorest (starlight and low contrast). As expected, "best" NVG acuities were achieved under system-optimal lighting conditions (twilight-moonlight) with targets of moderate to high contrast. Acuity degraded, however, with additional decreases in ambient illumination and/or contrast. At the lowest luminance and contrast level, acuity for three of the eight subjects degraded beyond measurable levels.

Table 1

Visual acuity with AN/PVS-5A night vision goggles under varying levels of brightness and contrast

	Minimum angle of resolution*		Snellen acuity**	
	Mean	Range	Mean	Range
<u>Twilight</u>				
High contrast	2.1	1.6 - 3.2	20/40	20/30-20/60
Moderate "	2.4	1.7 - 3.2	20/50	20/30-20/60
Low "	5.4	3.7 - 8.5	20/100	20/80-20/200
<u>Moonlight</u>				
High contrast	2.3	1.6 - 3.0	20/50+	20/30-20/60
Moderate "	3.5	3.0 - 4.5	20/60-	20/60-20/100
Low "	9.1	5.4 - 12.5	20/200+	20/100-20/300
<u>Starlight</u>				
High contrast	3.7	2.9 - 4.7	20/80+	20/60-20/100
Moderate "	5.7	3.9 - 7.5	20/100-	20/80-20/150
Low "	19.8	12.8 - 25.0	20/400	20/200-20/400+

* Minutes of arc.
** Approximate Snellen equivalent based upon letter sizes actually presented to the subjects.

<u>Acuity with reduced NVG brightnesses</u>:

The effects on acuity of reduced goggle output can be seen in Figures 4-6 (and in tabular form in Appendixes C-E). The data are presented as a function of percent NVG light transmission and target contrast for each level of ambient illumination. Each point represents the mean of eight subjects. Acuity is depicted both in terms of MAR and its associated Snellen equivalent. The means are plotted on log-linear axes and second order polynomial regression curves have been fitted to the data points. (Mean acuities greater than 20/400 on the graphs include the "no-response" estimates described above. In Appendixes C-E, these are depicted simply as a >20.0 MAR or as a Snellen equivalent of >20/400.)

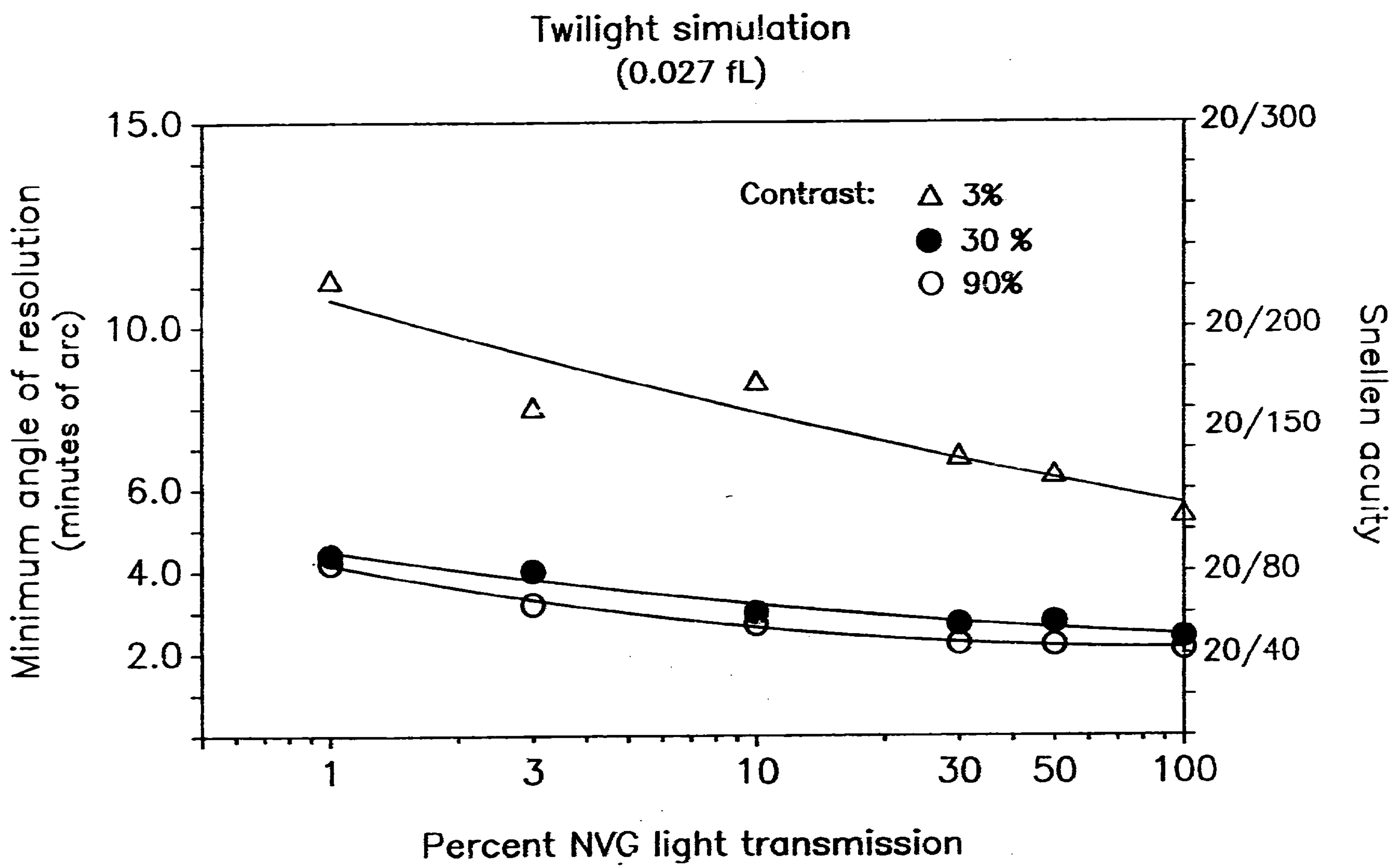

Figure 4. Visual acuity with NVGs under simulated twilight conditions: Effects of varying NVG light transmission and target contrast.

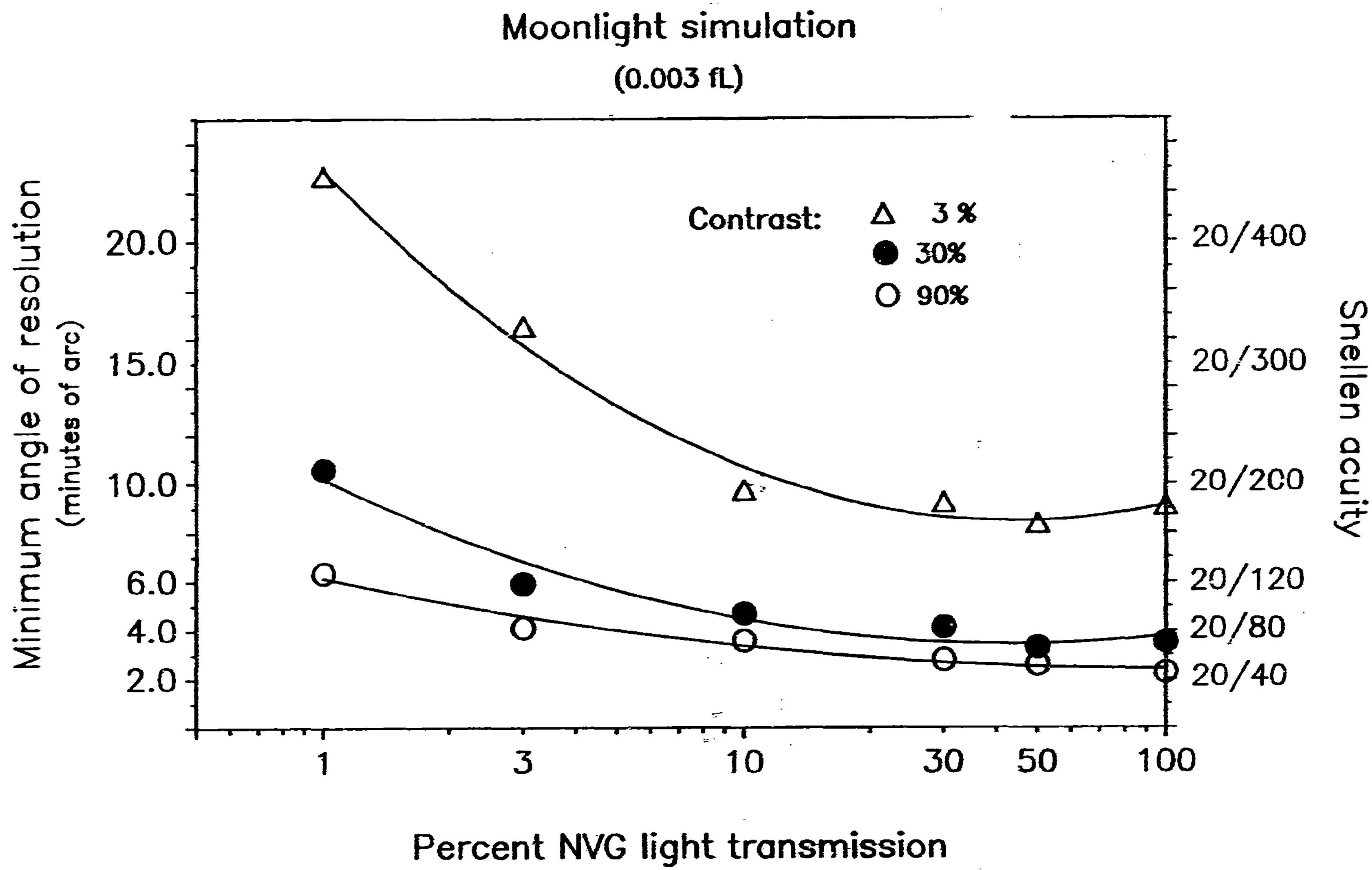

Figure 5. Visual acuity with NVGs under simulated moonlight conditions: Effects of varying NVG light transmission and target contrast.

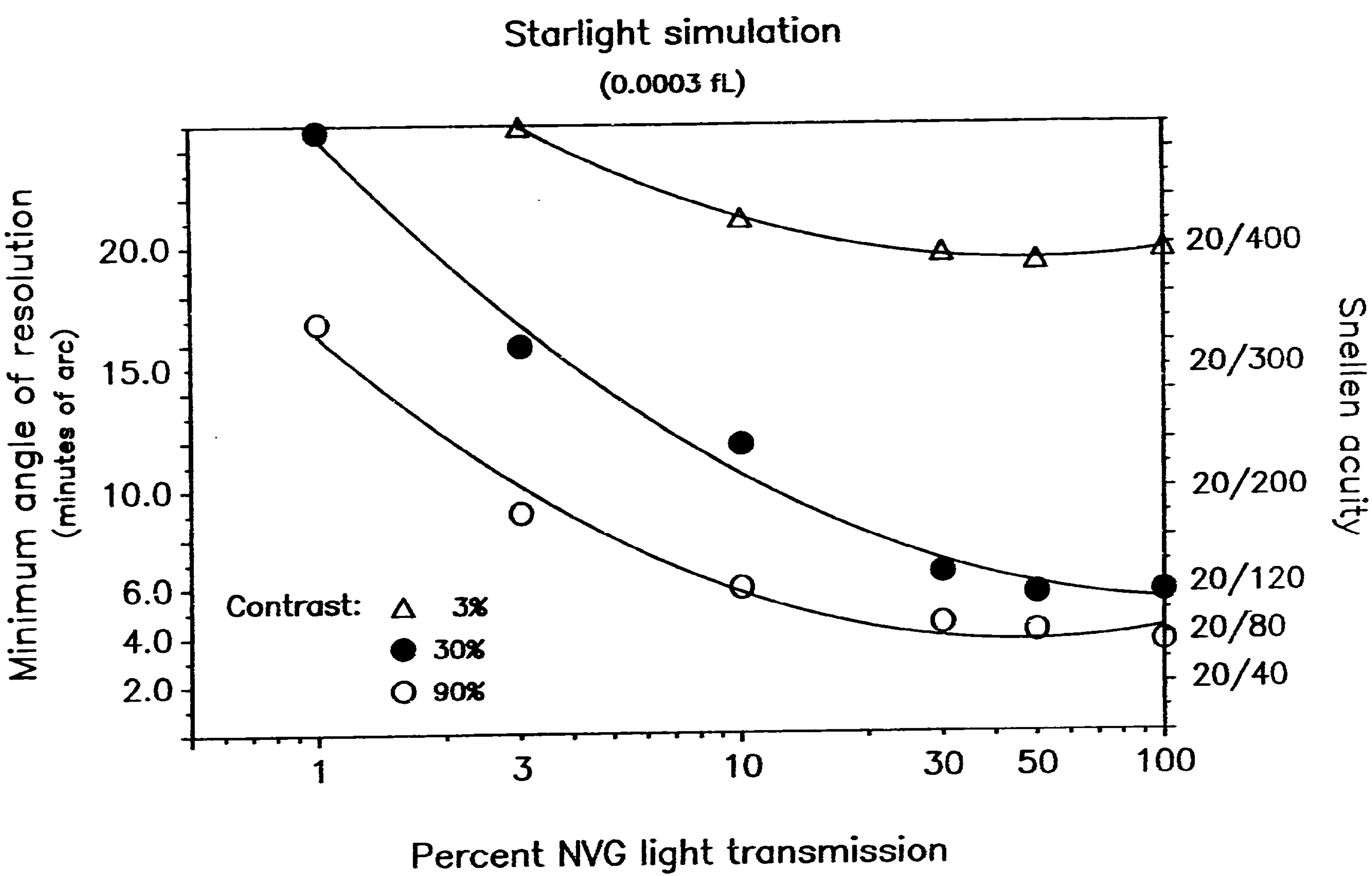

Figure 6. **Visual acuity with NVGs under simulated starlight conditions: Effects of varying NVG light transmission and target contrast.**

As can be seen, the specific effects of reducing goggle brightness varied as a function of both ambient light level and the target-background contrast. Under "good" NVG lighting (twilight and moonlight), acuities for medium to high contrast targets remained nearly unchanged from that of the no filter condition down to goggle brightnesses as low as 10 percent (Figures 4 and 5). At 3 percent transmittance, acuity degraded an additional 1-2 Snellen lines. At 1 percent transmittance, acuities ranged from 20/100-20/200 -- a more severe impairment. Under starlight conditions (Figure 6), acuities for both high and medium contrast targets maintained nonfilter levels down to a goggle transmittance of 30 percent. Below 30 percent transmission, acuities were more severely degraded. Acuities for low contrast targets generally were degraded under all viewing conditions, with or without filters. Under starlight conditions, acuity for targets of low contrast frequently was unmeasurable.

Discussion and conclusions

The results of this study provide data for acuity with NVGs under both "normal" (nonfiltered) and reduced luminous output. Without filters, goggle acuity is a function of both light level and target-background contrast. Acuity is maximal for targets of medium to high contrast under moonlit conditions or better. Acuity is degraded for low contrast targets and, for all contrasts, under starlight conditions. However, as our results demonstrate, NVG output can be reduced, in some cases by an order of magnitude, without impacting visual acuity adversely.

Under both twilight and moonlight conditions, acuities for all targets (high, medium, and low contrast) remained essentially unchanged or only minimally degraded from baseline conditions with goggle transmittances as low as 10 percent. (Acuity for low contrast targets was always lower than that for medium or high.) Below 10 percent transmittance, acuity showed moderate to severe impairment. Under starlight conditions, acuity remained unchanged from baseline conditions down to 30 percent of normal transmission, although initial baseline levels were higher and losses more dramatic beyond this level.

While these data provide direction, they are far from complete parametrically. For example, the data have been obtained under benign and static conditions, and potential visual impact(s) of spectral filtration have been ignored. Modifications to goggle output ultimately will require flight testing to determine both the impact on aviator performance as well as on aviator acceptance. Until such testing is accomplished, no firm conclusions should be drawn on the operational costs/benefits of tandem filter/NVG wear. Still, the data furnish an initial estimate of the effects of reduced goggle transmission on visual acuity and should provide a reliable baseline and a "look-up" capability with which to compare and evaluate visual performance with prototype ocular protective materials.

References

Levine, R. R., and Rash, C. E. 1989. Visual acuity with AN/PVS-5a night vision goggles and simulated flashblindness protective lenses under varying levels of brightness and contrast. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. (In press)

Michelson, A. A. 1927. Studies in optics. Chicago: University of Chicago Press.

RCA Corporation. 1974. Electro-optics handbook. Lancaster, PA.

Wetherill, G. B., and Levitt, H. 1965. Sequential estimation of points on a psychometric function. British journal of mathematical and statistical psychology. 18: 1-10.

Appendix A

DCD request memorandum

DISPOSITION FORM

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REFERENCE OR OFFICE SYMBOL	SUBJECT		
ATZQ-CDM-C (70-1i)	Evaluation of Visual Transmittance While Wearing Night Vision Goggles (NVG) and Nuclear Flashblindness Goggles		
TO Cdr, USAARL	FROM Dir, DCD	DATE Mr. Birringer/ncw/5272	CMT 1

1. The protection of the unaided eye against the effects of small tactical nuclear weapons (flashblindness) on the modern battlefield is an issue of concern for Army aviators. DCD is having difficulty defining the effects of reduced transmissivity of nuclear flashblindness goggles (PLZT) in terms of operational capability. This is particularly critical when aircraft are flying NOE at night and when pilots are wearing NVGs.

2. Request USAARL conduct an evaluation and analysis of the effects of visual transmittance through PLZT goggles worn in conjunction with NVGs. DCD will use this information to support or eliminate the operational capability currently required of the Aircrew Integrated Helmet (HGU-56/P). The HGU-56/P is currently in advanced development.

3. Also, request you provide a recommendation based on the analysis by 22 Nov 88.

4. DCD POC for this action is Mr. Birringer, extensions 5272/5071.

for Harold J. Brucker Ltc

THEODORE T. SENDAK
Colonel, Aviation
Director of Combat Developments

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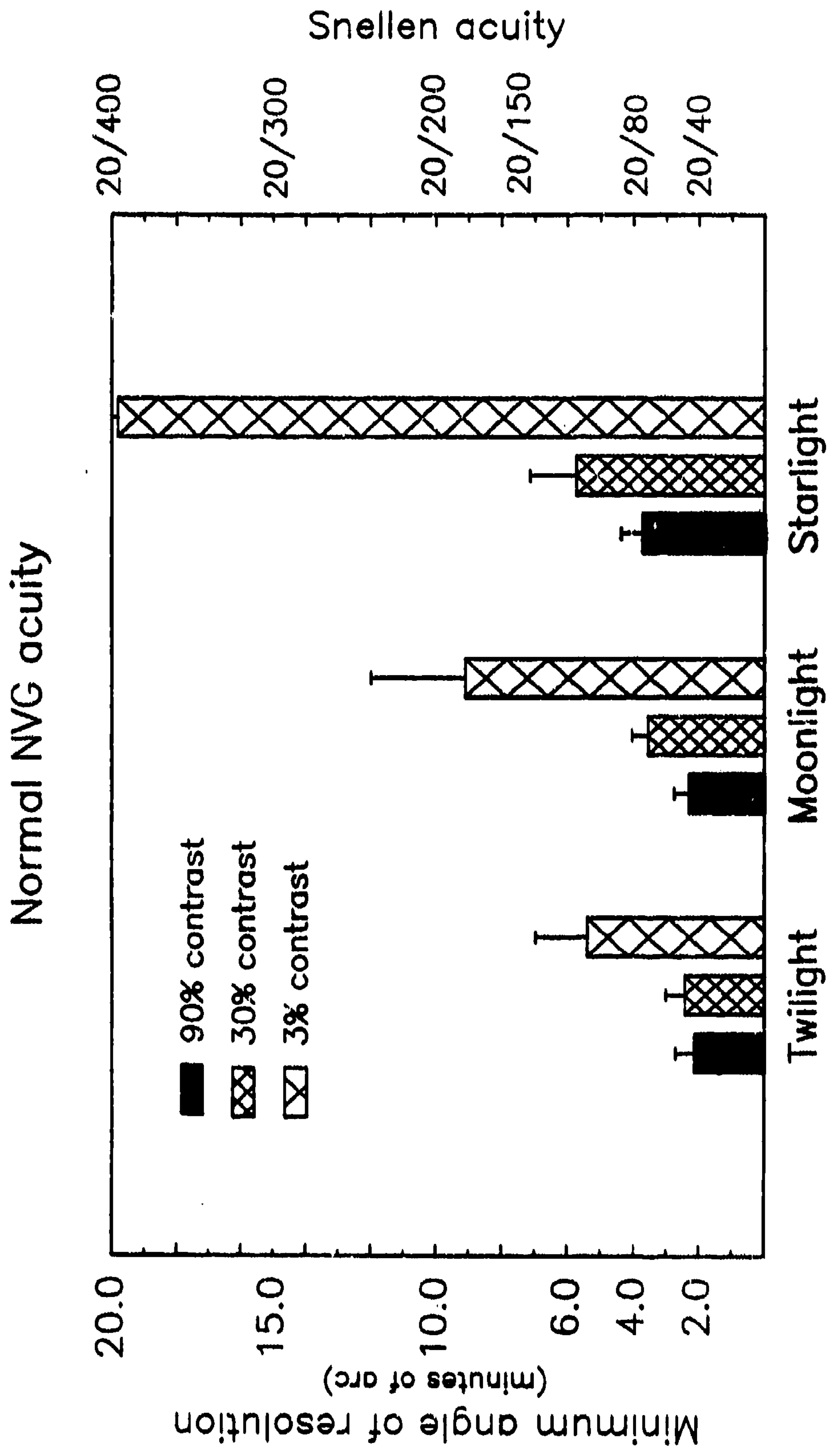
Appendix B

Normal NVG acuity under varying conditions of varying light levels and target-background contrasts


Normal NVG acuity
Snellen acuity
20/400
20/300
20/200
20/150
20/80
20/40
Minimum angle of resolution (minutes of arc)
20.0
15.0
10.0
6.0
4.0
2.0
90% contrast
30% contrast
3% contrast
Twilight
Moonlight
Starlight

Appendix C

Reduced NVG luminance: Acuity under "twilight" conditions

90% Contrast	Percent goggle transmission 100	50	30	10	3	1
Mean MAR	2.1	2.2	2.3	2.7	3.2	4.2
Range	1.6-3.2	1.7-3.3	1.4-3.6	1.8-4.4	1.8-5.6	3.3-5.6
Mean Snellen acuity	20/40	20/40	20/50+	20/50-	20/60	20/80
Range	20/30-20/60	20/30-20/60	20/30-20/80	20/40-20/80	20/40-20/100	20/60-20/100

30% Contrast	100	50	30	10	3	1
Mean MAR	2.4	2.8	2.8	3.0	4.0	4.4
Range	1.6-3.2	2.0-3.8	2.2-3.5	2.7-3.9	2.7-7.5	3.0-8.1
Mean Snellen acuity	20/50	20/60	20/60	20/60	20/80	20/80-
Range	20/30-20/60	20/40-20/80	20/40-20/80	20/50-20/80	20/50-20/150	20/60-20/150

3% Contrast	100	50	30	10	3	1
Mean MAR	5.4	6.4	6.8	8.7	8.0	11.2
Range	3.7-8.5	5.7-6.9	5.8-8.5	5.0-13.0	6.5-10.5	7.8-13.5
Mean Snellen acuity	20/100	20/150+	20/150	20/150-	20/150-	20/200
Range	20/80-20/200	20/100-20/200	20/100-20/200	20/100-20/300	20/150-20/200	20/150-20/300

Appendix D

Reduced NVG luminance: Acuity under "moonlight" conditions

90% Contrast	Percent goggle transmission					
	100	50	30	10	3	1
Mean MAR	2.3	2.6	2.8	3.6	4.2	6.4
Range	1.6-3.0	1.9-3.6	1.9-4.7	2.6-4.2	3.3-5.7	5.3-8.5
Mean Snellen acuity	20/50	20/50	20/60	20/80	20/80	20/150
Range	20/30-20/60	20/40-20/80	20/40-20/100	20/50-20/80	20/60 20/100	20/100-20/200

30% Contrast	100	50	30	10	3	1
Mean MAR	3.5	3.3	4.2	4.7	6.0	10.6
Range	2.9-4.5	2.5-4.0	3.1-7.3	3.3-6.8	4.9-9.8	5.8-17.5
Mean Snellen Acuity	[illegible]-	20/60	20/80	20/100	20/150+	20/200
Range	20/60-20/80	20/50-20/80	20/60-20/150	20/60-20/150	20/100-20/200	20/200-20/400

3% Contrast	100	50	30	10	3	1
Mean MAR	9.1	8.4	9.2	9.7	16.5	>20.0
Range	5.4-12.5	6.4-10.8	6.2-12.8	6.7-12.5	9.3->20.0	11.0->20.0
Mean Snellen acuity	20/200+	20/150-	20/200+	20/200+	20/300	>20/400
Range	20/100-20/300	20/150-20/200	20/150-20/300	20/150-20/300	20/200->20/400	20/200->20/400

Appendix E

Reduced NVG luminance: Acuity under "starlight" conditions

90% Contrast	Percent goggle transmission					
	100	50	30	10	3	1
Mean MAR	3.7	4.1	4.5	6.0	9.1	16.9
Range	2.9-4.7	3.0-5.8	3.4-6.1	4.5-11.5	5.8-13.0	12.8->20.0
Mean Snellen acuity	20/80+	20/80	20/100+	20/150+	20/200+	20/300
Range	20/60-20/100	20/60-20/100	20/60-20/150	20/100-20/200	20/150 20/300	20/200->20/400

30% Contrast	100	50	30	10	3	1
Mean MAR	5.7	5.7	6.6	11.9	15.9	>20.0
Range	4.1-7.5	4.4-7.5	5.1-9.8	6.2->20.0	12.0->20.0	>20.0
Mean Snellen Acuity	20/100	20/100	20/150-	20/200	20/300	>20/400
Range	20/80-20/150	20/80-20/150	20/100 20/200	20/200-20/400	20/200->20/400	>20/400

3% Contrast	100	50	30	10	3	1
Mean MAR	19.8	19.3	19.7	>20.0	>20.0	>20.0
Range	12.7->20.0	11.3->20.0	13.3->20.0	10.5->20.0	>20.0	>20.0
Mean Snellen acuity	20/400	20/400	20/400	20/400	>20/400	>20/400
Range	20/200->20/400	20/200->20/400	20/200->20/400	20/200->20/400	>20/400	>20/400

Appendix F

Manufacturers' list

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