

Peer Reviewed

Respirator Wear and Its Effects on Visual Acuity, Depth Perception, and Field of View

J.A. Whitley
DM. Caretti

U.S. Army Edgewood Research, Development, and Engineering Center
Aberdeen Proving Ground, MD 21010-5423

Abstract

This study assessed the differences between two military-type respirator masks with dissimilar lens sizes and configurations and no-mask variables for assessments of visual acuity, stereoacuity, and field of view. Performance variations between wearers' sex were also evaluated. Measurements for these visual tests were taken from 14 volunteer subjects (9 males and 5 females). Subjects were tested using Snellen test charts, the Frisby Stereotest, and the Marco Projection Perimeter. Each subject completed three trials (no mask, MASK 1, and MASK 2) in random order. MASK 2 had smaller lenses which were situated closer to the eyes than MASK 1. Data was recorded in the form of Snellen Fractions for visual acuity, disparity for stereoacuity, and degrees for field of view. Results indicated that stereoacuity improved during wear of MASK 1 compared to the control condition. Females performed better than males for all concepts on the stereoacuity task. Both MASK 1 and MASK 2 exhibited a significantly narrowed field of view compared to control, with MASK 1 imposing greater reductions in radial field of view limits than MASK 2, particularly at field axis positions in the inferior visual field. Binocular field of view areas were significantly less than control during wear of both masks. Field of view fusion areas decreased significantly during mask wear compared to control with MASK 1 exhibiting significantly greater reductions in field of view fusion areas compared to MASK 2. These findings suggest that the lens configuration and placement of MASK 2 improves peripheral vision capabilities compared to MASK 1.

Introduction

Respirator wear involves several integrated factors (e.g., respiratory burden imposed by breathing against a resistance, the obstruction of vision, the thermal burden caused by covering the face with an impermeable material, and psychological effects) that can affect a wearer's ability to perform assigned tasks (Johnson et al., 1992). Much of the focus of tests of performance during mask wear has been on the burden imposed on respiration. However, since the factors of mask wear are integrated, data

representing the effects of mask wear on visual, thermal, and psychological performance in conjunction with measures of the respiratory burden need to be generated. It is also important to predict how much overall performance is lost as a result of visual, thermal, psychological, and respiratory degradation.

Evaluation of the various mask factors does not necessitate testing of specific mask systems, because design technology has not changed dramatically over

the years. Therefore, two similar full facepiece respirators were used in this study which differed according to lens shape and placement on the facepiece. Of particular interest was whether visual performance differed between these masks due to differences in lens configurations between the masks. Therefore, the present study was designed to assess factors of visual acuity and depth perception and test monocular and binocular visual fields.

Procedure

Fourteen volunteers (9 males and 5 females) with a mean age of 23 ± 3 years participated in this study after giving their informed, voluntary consent. Participants did not wear any form of corrective lenses in this study and had visual acuities of 20/30 or better (Snellen Fractions ≥ 0.67). Average visual acuity of the subjects was better than 20/20, with only two subjects having a visual acuity of 20/30. In addition, subjects did not report having any history of visual problems and none wore corrective lenses. These criteria were chosen to eliminate the possibility that measures of visual performance during this study may be influenced by factors other than mask wear.

Measurements of visual acuity, depth perception, and visual field were obtained. Static visual acuity (VA) was measured binocularly using Snellen Test charts (Westheimer, 1991). Subjects were positioned 6 m away from the charts and asked to identify, by number, the line with the smallest letters that they could clearly see and read aloud the letters corresponding to that line. If an incorrect response was given, the subject was asked to read the next largest line of letters on the Snellen Chart. This pattern continued until the subject correctly identified all of the letters of the same line number on at least 3 different Snellen test charts. All VA measurements were recorded and then converted to a Snellen fraction (SF) equal to 20 divided by the recorded measurement.

Measurements of stereoacuity (SA) were obtained using the Frisby Stereotest (Rosner and Rosner, 1986) (Fig. 1). This test consists of three 17 cm^2 clear plastic plates of different thicknesses (1, 3, and 6 mm). Printed on one side of each plate are four random-dot patterns arranged symmetrically so that each plate appears the same to the viewer regardless of its alignment when presented. On the reverse side of each plate is one random-dot

This study was part of a larger study which tested the combined effects of mask wear and exercise of different intensities on visual factors. The data presented here expands upon the visual test differences neglecting any exercise effects.

pattern positioned so that it is centered behind one of the four square patterns. Individuals able to detect the disparity created by the thickness of the plate perceive this circular pattern as being 3-dimensional. By controlling the viewing distance and thickness of the plate being presented, a range of stereoacuities can be presented. Subjects viewed the various plates positioned in front of them at different distances from their eyes. Recordings of plate thickness and distance were taken after establishing the distance at which the subject was unable to reliably discriminate which of the four random-dot patterns contained the circle in-depth. Plates were viewed against a white background. Disparity, a measure of stereoacuity, was calculated using the equation

$$\text{Disparity} = 206264.81 (p \cdot dl) / 1.49 (l^2) \text{ seconds of arc}$$

where p is the interpupillary distance, l is the viewing distance, and dl is the plate thickness. Lower disparity values represent finer stereoacuity.

Measurements of field of view (FOV) were obtained using a Marco Projection Perimeter which uses kinetic perimetry with the eye at the center of rotation within a hemisphere that has a radius of curvature of 33 cm (Caretto, 1995). A small circle of light of fixed size (4 mm^2) and illumination (100 apostilbs) was projected onto the hemisphere's inner surface and moved from a non-seeing area to an area where it could just be seen by the subject whose monocular sight was fixed on the center of the hemisphere. Subjects responded to seeing the test object by depressing a hand-held button which, in turn, marked that position within the visual field on a chart designed for mapping of FOV (Fig. 2). For each assessment of FOV, 24 field axis positions distributed angularly about the center of the hemisphere in 15° increments from the horizontal and vertical meridians were tested. During monocular

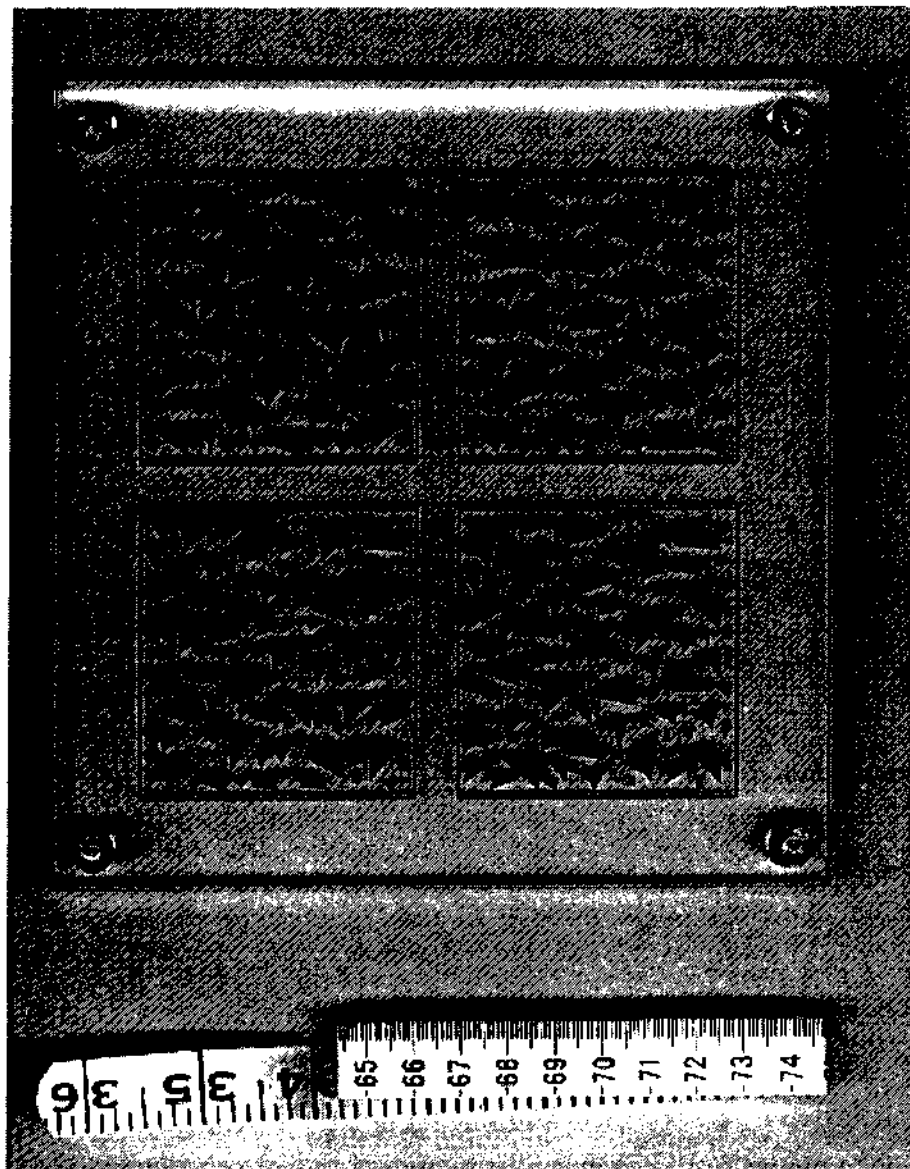
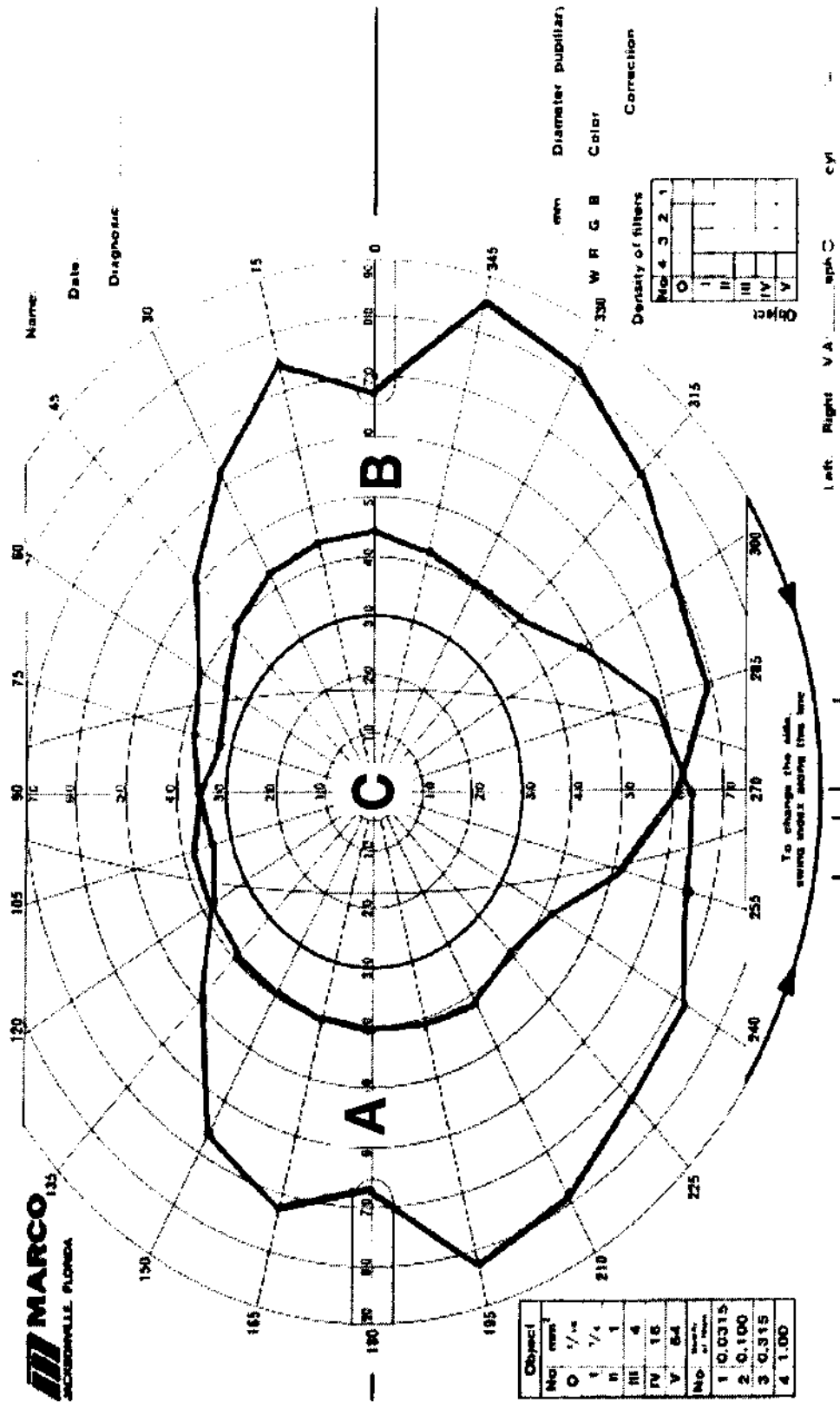


Figure 1. Some components of the Frisby Stereotest.



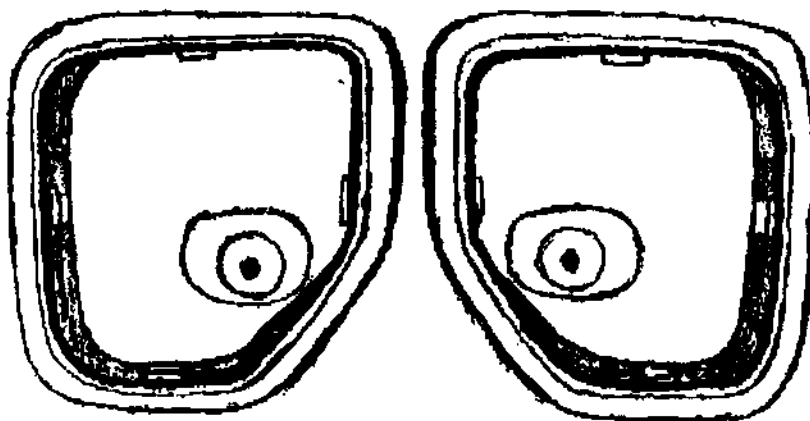
re 2. Sample Marco Projection Perimeter completed chart. Area (A) is the left eye area. Area (B) is the right eye area. Area (C) is the binocular fusion area.

FOV measurements, the non-test eye was covered with an eye patch to prevent binocular viewing.

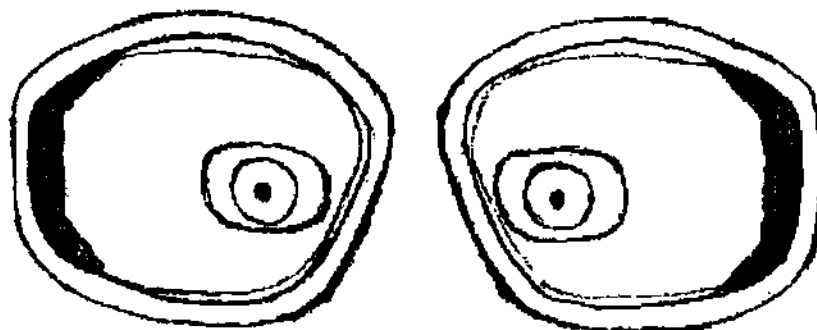
Radial limits of FOV were estimated from the FOV mapping charts for each of the 24 fieldaxis positions. Also, using the peripheral isopter for each monocular measurement of FOV, binocular FOV areas (cm^2) were estimated by overlapping left and right eye FOV charts and tracing the outer limit contours of both eyes. A Hewlett-Packard plotter (HP 7475A) and computer (HP 9236) were then used to quantify the binocular FOV areas. Binocular fusion area, an estimation of the area within the field of view where stereopsis will be perceived, was also

approximated from overlapping areas of left and right eyes (Fig. 2).

Figure 3 illustrates the lens configuration of the two military, full face-piece negative pressure respirators (MASK 1 and MASK 2) used for testing. Both masks were made of a silicone rubber facepiece with a reflected peripheral seal and molded-in headharness buckles. Both masks were worn with an air filtering canister mounted on the left side. Binocular mask lenses were part of the facepiece of each mask. Optical characteristics (i.e., refractive power, haze, and prism) of the lenses were identical for the two masks. However, the lenses of MASK 2



A - MASK 1



B - MASK 2

Figure 3. Drawings depicting eye lens configuration and shape of (A) MASK 1 and (B) MASK 2.

were smaller than those of MASK 1 and were mounted closer to the eyes of the wearer. Lenses were checked for defects such as scratches and marks before use. Mask lens characteristics are indicated in Table 1. Subjects were properly fitted for each mask before testing commenced by a test administrator experienced in mask fitting. Determination of the best size mask for each subject was based on factors of location of the mask periphery on the forehead, cheeks and chin, position of the respirator nosepiece on the bridge of the wearer's nose, and position of

the wearer's eyes in relation to the optical center of the mask lenses.

Data were analyzed using a 2-way MANOVA to determine the effects of the wearer's sex (male, female) and mask (control, MASK 1, MASK 2) on VA and SA measurements. Radial FOV limits were analyzed with a 4-way ANOVA testing the effects of eye (left, right), sex, mask, and field axis position (in degrees). Significance was accepted at the $p < 0.05$ level.

Results

Visual Acuity and Stereoacuity

In addition to effects shown in Table 2, some other statistical effects should be mentioned. The overall range of VA values were from 0.5-2.0 with a mean of 1.18 ± 0.34 . SA range was quite large (33.6-140.6) with a mean of 65.3 ± 20.4 . A MANOVA summary of all effects indicated a significant main effect for sex ($p < 0.01$). Independent of sex, a significant mask effect was found for SA. Also, when a sex and mask interaction effect was performed, a significant interaction for SA was observed. Scheffe Post Hoc analyses indicated that, overall, females performed better than males on SA ($p < 0.005$).

Interestingly, MASK 1 performed better on SA than control ($p < 0.05$).

Field of View Assessments

Radial limits ranged from 0.46° - 85.0° with a mean of $43.1^\circ \pm 18.2^\circ$. Average radial limits of monocular FOV estimated from the FOV mapping charts were not significantly influenced by gender for measurements taken for both eyes. However, a significant interaction between mask and field axis position was found. In addition, interactions among concept, eye, and field axis position were found.

Table 1. General mask lens specifications.

	MASK 1	MASK 2
Vertical height	7.10	4.55
Horizontal length	8.65	7.30
Approximate eye relief	3.90	2.10
Left-right distance (between lens centers)	11.50	9.80

* Eye relief is the distance between the mask lens and the surface of the eye's pupil.

Table 2. Average visual acuity and stereoacuity measures.

	VA (SF)		SA (sec-of-arc)	
	Male	Female	Male	Female
Control	1.05 ± 0.38	1.15 ± 0.30	69.4 ± 22.8	72.2 ± 27.8
MASK 1	1.19 ± 0.37	1.25 ± 0.29	$67.4 \pm U.I$	51.8 ± 9.50
MASK 2	1.18 ± 0.32	1.34 ± 0.29	71.0 ± 21.0	50.7 ± 12.1

Tables 3 and 4 represent average radial FOV degree limits of the left and right eyes, respectively. Both masks produced significant decreases in radial FOV limits of the left and right eyes when measurements were obtained. Left eye monocular FOV limits were significantly restricted during MASK 1 wear

compared to control at field axis positions of 0° to 45° and 225° to 345°. Compared to control, MASK 2 significantly narrowed FOV limits at field axis positions of 0° to 30° and 195° to 345°. The FOV limit restrictions imposed by MASK 1 were significantly greater than those imposed by MASK 2 at field axis

Table 3. Monocular FOV limits of each condition for the left eye.

Field axis position	FOV limit (degrees)		
	Control	MASK 1	MASK 2
0	49.7 ± 4.85*	15.3 ± 3.58	33.1 ± 15.5
15	49.8 ± 5.98*	20.9 ± 3.72	37.8 ± 18.2
30	47.2 ± 8.20*	24.2 ± 8.62	36.6 ± 17.0
45	43.1 ± 8.04*	28.0 ± 9.41	34.8 ± 13.7
60	40.3 ± 8.21	32.8 ± 8.02	34.5 ± 11.0
75	39.7 ± 8.70	33.4 ± 8.57	35.3 ± 8.54
90	38.1 ± 8.01	33.7 ± 7.54	35.9 ± 7.30
105	39.5 ± 8.29	35.8 ± 6.80	39.8 ± 6.87
120	44.8 ± 9.37	43.0 ± 7.92	42.3 ± 6.92
135	51.5 ± 10.5	50.3 ± 7.06	51.5 ± 8.71
150	60.9 ± 7.97	61.7 ± 4.87	58.7 ± 11.6
165	68.0 ± 5.43	67.8 ± 4.22	63.3 ± 15.5
180	65.0 ± 1.41	63.7 ± 2.81	57.4 ± 16.1
195	76.6 ± 3.53*	70.2 ± 8.02	62.5 ± 21.3
210	75.8 ± 3.98*	67.6 ± 8.65	55.4 ± 18.9
225	72.3 ± 4.03*	58.0 ± 8.75	45.2 ± 13.5
240	69.6 ± 4.47*	43.4 ± 10.9	37.3 ± 11.1
255	63.6 ± 4.07*	32.5 ± 11.6	32.7 ± 8.77
270	57.4 ± 5.11*	21.9 ± 7.96	27.1 ± 5.80
285	52.3 ± 2.28*	17.5 ± 6.78	25.6 ± 5.81
300	46.1 ± 3.98*	15.7 ± 6.20	24.6 ± 5.60
315	42.6 ± 3.51*	13.9 ± 6.18	25.9 ± 8.19
330	44.6 ± 4.85*	14.3 ± 6.20	27.7 ± 10.6
345	47.7 ± 4.20*	14.6 ± 6.08	30.8 ± 16.3

Table 4. Monocular FOV limits of each condition **for** the right eye.

Field axis position	FOV limit (degrees)		
	Control	MASK 1	MASK 2
0	63.4 ± 1.38	61.5 ± 3.58	55.8 ± 17.2
15	70.7 ± 5.14	66.7 ± 3.72	60.4 ± 16.3
30	59.9 ± 8.43	58.4 ± 8.62	49.5 ± 18.1
45	49.9 ± 9.80	45.6 ± 9.41	45.0 ± 8.30
60	43.7 ± 8.68	37.1 ± 8.02	39.6 ± 7.25
75	40.1 ± 7.82	34.6 ± 8.57	35.9 ± 7.59
90	37.9 ± 6.39	32.0 ± 9.39	34.3 ± 8.06
105	39.3 ± 6.63	31.1 ± 7.19	31.9 ± 7.40
120	41.2 ± 6.42*	29.2 ± 5.64	32.8 ± 9.51
135	43.7 ± 6.14*	26.9 ± 7.00	33.6 ± 11.0
150	47.0 ± 5.70*	23.2 ± 7.84	35.4 ± 14.3
165	48.8 ± 4.47*	20.8 ± 8.56	36.1 ± 16.1
180	50.2 ± 3.96*	18.7 ± 8.35	34.0 ± 13.5
195	46.8 ± 3.68*	19.1 ± 8.68	33.7 ± 14.9
210	43.7 ± 3.58*	16.4 ± 7.84	29.1 ± 8.82
225	41.1 ± 3.07*	15.9 ± 7.63	26.8 ± 5.50
240	46.0 ± 6.33*	17.5 ± 7.47	26.4 ± 4.67
255	52.1 ± 3.71*	20.1 ± 8.59	28.4 ± 6.01
270	52.0 ± 7.09*	26.8 ± 7.82	31.2 ± 7.11
285	61.3 ± 4.01*	34.6 ± 8.98	34.4 ± 11.3
300	65.1 ± 6.41*	43.9 ± 11.4	38.4 ± 12.9
315	72.8 ± 5.69*	57.7 ± 10.3	46.4 ± 16.4
330	75.5 ± 5.18*	66.0 ± 8.34	55.3 ± 21.0
345	75.3 ± 4.30*	69.6 ± 3.88	60.6 ± 20.7

positions of 0° to 30° and 315° to 345°. However, unlike the results with the right eye, MASK 2 had significantly lower FOV limits than MASK 1 at the field axis position of 225°.

Right eye monocular FOV limits were significantly narrowed during MASK 1 wear compared to

control at field axis positions of 120° to 315°. During wear of MASK 2, right eye FOV limits differed significantly from control values at field axis positions of 150° to 345°. Comparison of MASK 1 and MASK 2 FOV limits showed that MASK 1 manifested significantly greater reductions than MASK 2 at field axis positions of 150° to 225°.

Binocular FOV area (cm^2) of males was significantly less than females, but gender had no significant interactions with mask effects. Binocular FOV areas were significantly less during wear of MASK 1 ($132.4 \pm 13.4 \text{ cm}^2$) and MASK 2 ($125.9 \pm 12.1 \text{ cm}^2$) compared to control ($178.1 \pm 17.3 \text{ cm}^2$). Binocular fusion areas approximated from overlapping areas

of left and right eyes illustrated this same trend. Field of view fusion areas decreased significantly from the control condition ($94.9 \pm 11.9 \text{ cm}^2$) during mask wear with MASK 1 ($23.2 \pm 8.1 \text{ cm}^2$). Gender variables did not significantly influence FOV fusion area measurements.

Discussion

This study was designed to assess visual factors of mask wear under the condition of rest. Data indicated that females performed better than males for all concepts on tasks for visual acuity and **stereoacuity**. Many reasons for these findings are possible. One study illustrates that females display a higher degree of visual imagery than males. Females may also be able to process more visual information faster than males (McGuinness, 1976). Difference in **interpupillary** distances of females and males may help to explain our findings. The smaller interpupillary distances usually found in females may predispose them to better performance than males in these visual tasks because of this facial structure characteristic. However, interpupillary distances were statistically similar between the male and female subject groups in this study. Perhaps females are better focused and can interpret the Frisby Stereotest better than males. However, another study indicates that males are better at performing a disembedding **task**, which tests the ability to respond to a stimulus object without being distracted by its context (Lips, Myers, and Colwill, 1978). This test was very similar to the Frisby Stereotest task. One final explanation for the observed sex differences may have to do with minor differences in visual capabilities between the subject groups such as differences in monocular static visual acuities, binocular coordination of eye muscles, and minor refractive errors. Additional research that controls for these factors may be better able to determine reasons for the sex differences in visual capabilities observed in this study.

Wear of both masks improved stereoacuity compared to control conditions, with MASK 1 exhibiting a significant improvement compared to control. An explanation for the observed improvements in stereoacuity during mask wear is not readily apparent. Increased arousal caused by the stress of mask wear could cause improved subject attention resulting in better concentration while performing the Frisby Stereotest. Low levels of

stress have previously been shown to stimulate performance (Poulton, 1976). In addition, visual field narrowing associated with mask wear may have served to improve subject visual attention to the task by "filtering" peripheral distractions. The interaction of both peripheral narrowing and increased arousal may explain the improved stereoacuities observed during mask wear.

Mask wear significantly limited peripheral vision for both the left and right eyes. This finding was not unexpected. However, the methods employed to measure and assess field of view enabled us to identify precisely where decrements in visual field were most significant during mask wear. It is understood that there is a wide individual variability in respirator visual fields mostly due to differences in facial structures (Zelnick et al., 1994). However, in general, mask wear severely decreased radial FOV limits at field axis positions from 180° to 345° , or at all positions below the horizontal meridian for all such individuals. Within this range of field axis positions, MASK 1 usually exhibited greater reductions in radial FOV limits compared to MASK 2. This suggests that the configuration and placement of lenses on MASK 2 limit the narrowing of peripheral vision during mask wear. How the improved peripheral vision capabilities of MASK 2 would affect overall performance is not readily apparent. However, the tasks requiring significant visual input should benefit from improved FOV capabilities. Also, for the control condition, the right eye performed better than the left eye. However, this was probably due to the canister placement on the mask.

Assessment of binocular FOV fusion areas showed significantly greater fusion areas with MASK 2 compared to MASK 1. This finding suggests that the potential area for stereopsis to be perceived was greater during wear of MASK 2 compared to MASK 1. Therefore, the MASK 2 design seems to provide for potentially better visual input

within the field of view compared to MASK 1. However, since the binocular fusion area is only an estimation of the area within the field of view where

stereopsis will be perceived, this conclusion is only speculative.

Conclusions

Females performed better than males for all concepts on the task of stereoacuity. Stereoacuity actually improved during wear of the MASK 1 respirator compared to the no mask condition. Field of view was significantly narrowed during mask wear, with MASK 1 imposing greater degradation in radial FOV limits compared to MASK 2. In addition, FOV degree limits for MASK 1 were lower than MASK 2 FOV degree limits at many field axis positions below the horizontal meridian. Both binocular field of view areas and field of view fusion

areas decreased significantly during mask wear compared to control. MASK 1 showed significant degradation compared to MASK 2 in fusion areas. These findings suggest that the configuration and placement of the lenses within the MASK 2 facepiece act to limit the narrowing of peripheral vision associated with mask wear. Thus, it appears that the lens design of MASK 2 is more preferable than that of MASK 1 based on these visual acuity, depth perception, and field of view findings.

References

1. Caretti, D.M., "Signal Detection Over the Visual Field During Wear of Various Respirators and Respirator Configurations." (ERDEC Technical Report No. 247) U.S. Army Edgewood Research, Development, and Engineering Center, Aberdeen Proving Ground, Edgewood, MD (1995).
2. Johnson, A.T., R.A. Weiss, and C. Grove, "Respirator Performance Rating Tables for Mask Design," *Am. Ind. Hyg. Assoc. J.* 53:193-202 (1992).
3. Lips, H.M., A. Myers, and N.L. Colwill, "Sex Differences in Ability: Do Men and Women Have Different Strengths and Weaknesses?" *The Psychology of Sex Differences* Prentice-Hall Inc., NJ (1978).
4. McGuinness, D., "Sex Differences in the Organization of Perception and Cognition," *Exploring Sex Differences* Academic Press, NY (1976).
5. Poulton, E.C., "Arousing Environmental Stresses Can Improve Performance, Whatever People Say," *Aviat. Space Environ. Med.* 47:1193-1204 (1976).
6. Rosner, J., and J. Rosner, "Filter-Free Method for Assessing Farpoint Stereopsis: A Pilot Study Report," *Am. J. of Optm. & Physio. Opt.* 63:978-980 (1986).
7. Westheimer, G., "Visual Acuity," *Adler's Physiology of the Eye*, Seventh edition, Mosby Co., St. Louis, pp. 531-547 (1991).
8. Zelnick, S.D., R.T. McKay, and J.E. Lockey, "Visual Field Loss While Wearing Full-Face Respiratory Protection," *Am. Ind. Hyg. Assoc. J.* 55:315-321 (1994).