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Effects of Full Face-Piece Respirator Design on Detection of Peripherally Located Stimuli

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Abstract

Reaction time for detection of light signals distributed throughout the visual field was assessed during wear of a dual lens, face-mounted air-purifying canister mask (DLFM) and a single lens, remotely placed air-purifying canister mask (SLR) to determine the effects of each design on wearer detection sensitivity. Mask performance ratings for radial limits of field of view were also assessed for each condition. Although both the DLFM and SLR respirators resulted in a decrease in visual field performance ratings, the magnitude of detriments was significantly greater with the DLFM mask. Response time for signal detection increased with greater peripheralization of light locations for DLFM, SLR, and control conditions. However, mean reaction time during wear of the DLFM respirator was significantly greater than reaction time during wear of the SLR mask for peripheral rings positioned at 38°, 64°, and 90° from the central line of sight. Wear of the DLFM mask also resulted in the worst performance for stimuli located superior and inferior to the horizontal axis of view. These results clearly indicate the detrimental effects of a dual lens, face-mounted air-purifying canister respirator design on signal detection sensitivity.

Introduction

Location and detection of events or signals of various kinds likely to occur anywhere in the field of view are considered to be critical to the effective performance of operator tasks (Kobrick and Sleeper, 1986). The elapsed time required for response to signals perceived in various positions in the normal field of view contributes an additional dimension to central viewing for tasks such as surveillance, display monitoring, and even visual inspection. Many conditions can act to degrade an individual's detection capability (e.g., pathology, environmental

extremes, and others). Likewise, when visual field is degraded as a result of full face-piece respirator wear, the ability of a worker to visually detect peripherally located events or signals may also be significantly impaired. However, little is known about the effects of full face-piece respirator wear on detection of signals in the limited visual field afforded by such masks.

Major considerations for assessing the effects of a full face-piece respirator on detection capability are

the design and placement of the respirator eye-piece and air-purifying filters. The scope of full face-piece respirators available today typically offers users one of two lens design choices and multiple air-purifying configurations. Such respirators commonly are made with either dual eye-lenses or a single lens extending virtually the entire width of the face-piece. Also, full face-piece masks often have air-purifying filters attached somewhere on the respirator's face piece. Such design characteristics severely decrease the user's overall visual field. This effect is most profound within the lower visual field (McAlister

et al., 1991; McAlister and Buckingham, 1993; Caretti and Bay-Hansen, 1994).

This paper reports the results of a study designed to assess signal detection capability during full face-piece respirator wear. Specifically, the effects of two different respirator designs, one dual lens respirator with a face-mounted air-purifying canister and one single lens respirator with the air-purifying element mounted off of the face, on the ability to detect visual signals throughout the visual field were investigated.

Experimental Procedures

Twenty-four subjects (12 male and 12 female) with the mean age of 23 ± 3 years participated in this study. Since corrective lenses were not available for the respirators used in this study, only individuals who demonstrated monocular visual acuities of 20/20 or better were selected as volunteers. Volunteers were thoroughly briefed on the nature and purpose of the study and informed consent was obtained from each volunteer prior to participation. All experimental procedures were conducted at room temperature (20–24°C).

Measurements of absolute limit contours of the binocular 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. A small circle of light of fixed size (4 mm²) and illumination (10 milli-lambert) 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 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. 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 (Figure 1). All measurements were taken binocularly with the midpoint between each subject's eyes as the center of rotation within the hemisphere.

The Marco Projection Perimeter is designed for clinical assessment of visual field and provides accurate and reproducible data on the state of the absolute limit contours of the visual field. However, the visual task on which the perimeter is based bears

little resemblance to commonplace viewing. Therefore, detection sensitivity of the overall binocular visual field was measured with a perimeter and computer system developed specifically for this purpose (Kobrick *et al.*, 1987). In brief, it requires an individual to monitor stimulus lights distributed about the visual field when activated intermittently and in a random pattern of locations. The individual's detection efficiency is judged on his response time for signal detection. As a modified version for the current study, the stimulus configuration of this perimeter consists of a hemispheric array of 32 units of light emitting diodes (LEDs) arrayed along eight radial axes dispersed about the subject's central line of sight. The eight curved ribs of the structure were spaced at 45° intervals to form a 81.3 cm diameter hemisphere. The LEDs were positioned on each of the eight ribs at 12°, 38°, 64°, and 90° angular displacement from the center of the hemisphere (Figure 2). The common radius of the hemispheric rib structure (40.6 cm) set all the stimulus lights at the same distance from the viewing position, and thus subtended the same visual angle. All metal surfaces of the rib structure were painted flat black and the back side of the entire assembly was enclosed in a black fabric cover.

Prior to administration of the signal detection task, subjects were seated in a contoured seat with an adjustable headrest. The seat was positioned so that the subject's line of sight intersected the center of the hemisphere and the edge of the hemisphere abutted the peripheral limit of the visual field at 90°. Subject head movements were partially restrained by both the seat headrest and a foam pillow placed between the back of the subject's head and the headrest. Even so, subjects were directed to avoid moving their heads as much as possible.

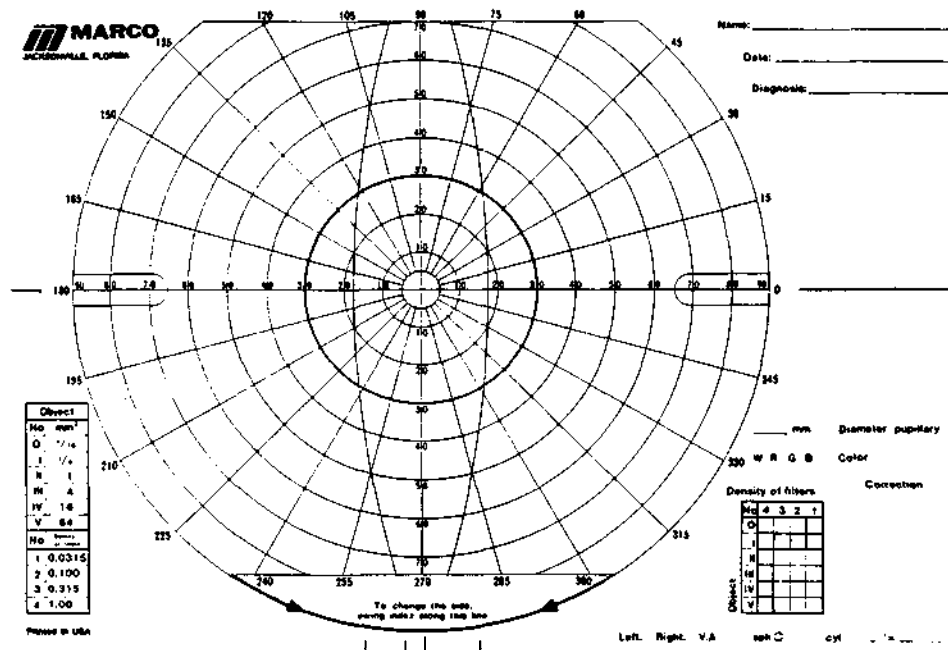


Figure 1. Visual field mapping chart used to measure absolute limit contours of the binocular field of view (FOV) with the Marco Projection Perimeter.

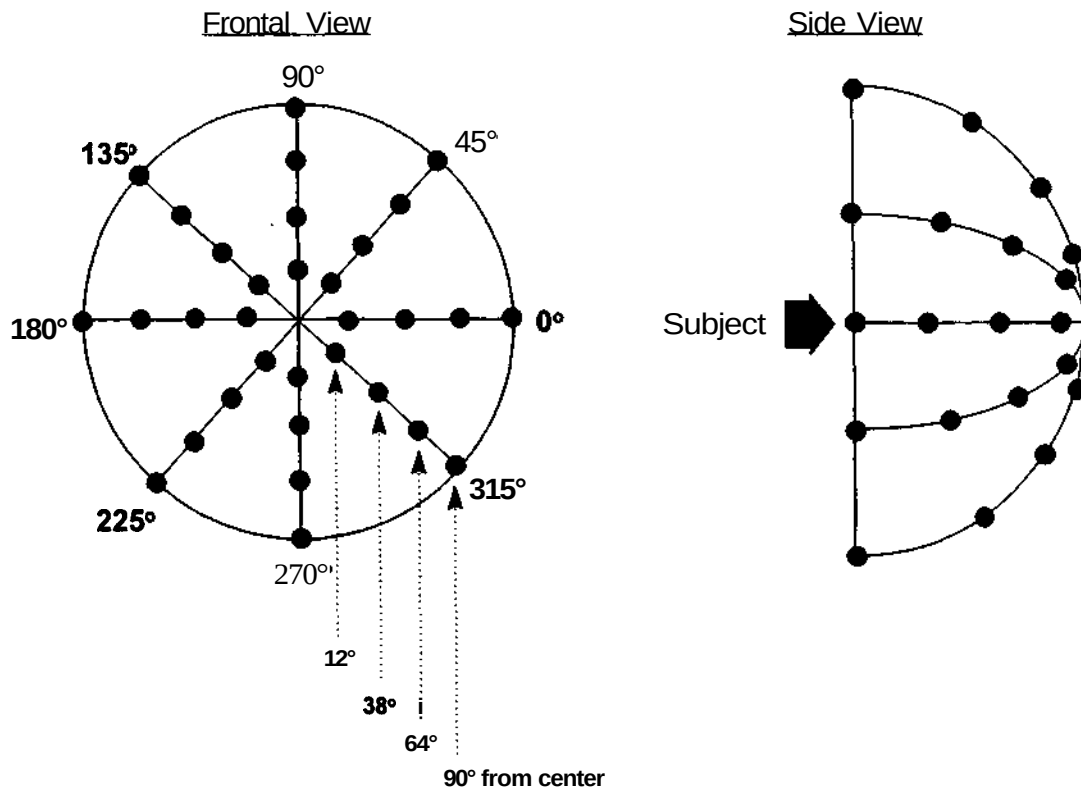


Figure 2. Schematic diagram of the signal detection perimeter.

Subjects were instructed to view the display continuously while fixing their sight on its center, and to depress a hand-held button whenever the onset of a signal light was detected. In each test run, subjects received all 32 stimulus lights presented in random order. A Hewlett-Packard 9236 Computer controlled signal presentation and recorded each subject's response times. The time intervals between occurrences of stimuli were randomized at 5 to 25 seconds so that the subjects could not anticipate the time of onset or location of any stimulus. An undetected stimulus was considered to be missed after 5 seconds and was given a response time score of that value.

Measurements of absolute limit contours and detection sensitivity over the binocular visual field for each mask wear condition were randomized. The dual lens, face-mounted filter (DLFM) configuration was achieved by wear of the U.S. Army M40 respirator. For the DLFM wear trial, a C2 air-purifying canister was mounted on the left side of the respirator. The single lens, remotely located filter (SLR) arrangement involved wear of a prototype respirator. For this mask, the remote air-purifying filter element was connected to the mask inspiratory ports with short rubber ducts and hung inferior to the face piece

in the area of the wearer's chest. The location of the air-purifying filter caused problems with placement of a subject's head within each perimeter because it interfered with the chin rest assemblies. However, since the connecting hoses and attachment pieces were not visible to the wearer at any time, the filter element was removed from the SLR mask for testing. A no mask trial was completed as the control condition for the study.

All FOV limit contour data were analyzed as mask performance rating measures according to the methods of Jonhson *et al.* (1992). Mask performance ratings were calculated as (mask results/control results) x 100. Therefore, a mask performance rating represents a percent of the control (no mask) condition. Analysis of variance (ANOVA) was used to compare mask FOV limit contour performance ratings between the DLFM and SLR results. A separate ANOVA performed to compare reaction time data of the signal detection task between the control, DLFM, and SLR mask configurations revealed a non-parametric distribution of the reaction time data. Therefore, non-parametric ANOVA was executed to assess the effects of the experimental conditions on reaction time data. For all analyses, significance was accepted at the $p < 0.05$ level.

Results

Absolute Limit Contours of the Binocular FOV

Mask performance ratings for absolute limit contours in the binocular FOV demonstrated that decreases were most prominent within the inferior FOV (Table 1). Decrements of approximately 50% and greater were observed for the DLFM condition within the inferior visual field, specifically at field axis positions of 240° through 300°. The SLR prototype mask elicited a performance decrement of greater than 50% only at the field axis position of 270°. Performance decrements were significantly greater during wear of the DLFM respirator compared to the SLR mask at axis positions ranging from 45° to 135° in the superior visual field and from 210° to 330° in the inferior visual field.

Signal Detection

Separate Kruskal-Wallis analyses of variance for the select conditions of peripheral lamp location were performed to determine differences in reaction time between test conditions. Group mean reaction

times for each peripheral ring of stimuli (12°, 38°, 64°, and 90°) are shown in Figure 3 with each experimental condition represented by a separate curve. The means for the rings reflect the effect of peripherilization of the stimulus (Kobrick and Sleeper, 1986). Mean reaction time increased with greater peripherilization of the light signals within all experimental conditions. Between group comparisons determined using the Mann-Whitney U test for 2 independent samples showed that impairments were significantly greater for the DLFM mask wear condition compared to the control condition at all light signal locations. In addition, mean reaction time during wear of the DLFM respirator was significantly greater than reaction time during wear of the SLR mask for peripheral rings positioned at 38°, 64°, and 90° from the central line of sight.

Overall group mean reaction times from each test condition for the four stimuli on each of the eight axes are presented in Figure 4. The means for the axes indicate the effect of the stimulus' general location in the overall visual field (Kobrick and Sleeper, 1986). Compared to the control condition,

Table 1. Performance ratings (%) for radial degree limits.

Axis	SLR	DLFM
0	99.9 ± 3.2	98.7 ± 4.0
15	96.5 ± 8.9	97.1 ± 8.0
30	94.8 ± 10.8	93.5 ± 12.8
45	96.0 ± 12.1	84.6 ± 16.4 *
60	97.5 ± 13.4	82.1 ± 18.2 *
75	94.4 ± 12.0	78.3 ± 17.1 *
90	92.5 ± 11.3	74.4 ± 15.4 *
105	92.6 ± 9.5	74.7 ± 16.2 *
120	95.9 ± 11.1	78.3 ± 15.7 *
135	94.8 ± 10.7	83.1 ± 14.8 *
150	94.9 ± 8.1	92.7 ± 8.9
165	97.2 ± 5.6	95.0 ± 6.3
180	99.2 ± 2.0	97.8 ± 7.6
195	96.4 ± 3.6	94.7 ± 8.0
210	96.8 ± 5.9	85.4 ± 21.2 *
225	87.3 ± 9.2	57.0 ± 7.6 *
240	74.3 ± 13.4	47.7 ± 11.0 *
255	55.8 ± 13.5	31.6 ± 10.5 *
270	49.2 ± 13.7	28.8 ± 10.2 *
285	55.4 ± 13.6	35.1 ± 12.4 *
300	70.7 ± 16.3	51.3 ± 16.4 *
315	83.7 ± 12.0	67.7 ± 11.8 *
330	94.4 ± 7.3	86.4 ± 7.5 *
345	97.2 ± 6.5	93.9 ± 7.1

* Indicates significant differences between respirator types.

reaction time during mask wear was most impaired in the inferior (225° to 315°) visual field area. Average reaction time during SLR mask wear was statistically similar to control values at all field axis positions with the exception of the 270° axis position. Mean response time differed significantly between

both the control and SLR mask conditions compared to the DLFM mask condition at field axis positions of 45°, 90°, 135°, 225°, 270°, and 315° axis position. However, no significant differences were found between conditions along the horizontal axis of view (i.e., axis positions at 0° and 180°).

Discussion

The results of the present study provide further verification of previous findings that field of view is significantly narrowed during full face-piece respirator wear, particularly within the lower visual field (McAlister *et al.*, 1991; McAlister and Buckingham, 1993; Caretti and Bay-Hansen, 1994).

The performance ratings within the inferior visual field associated with the SLR concept respirator demonstrate that the lens design and filter placement of the mask is less visually inhibiting than the DLFM mask tested in this study. The SLR concept used a single lens which extended the entire width of the

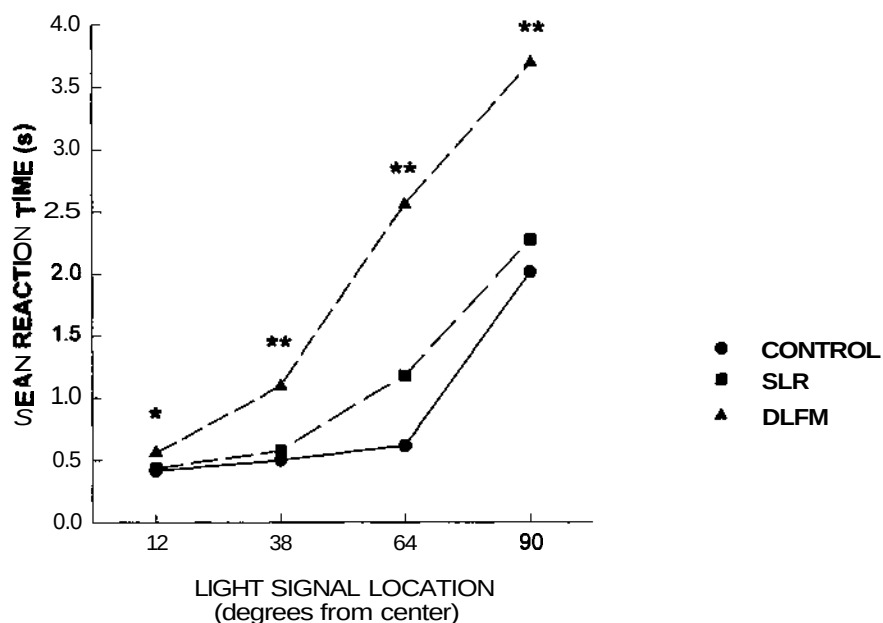


Figure 3. Mean reaction time at each peripheral light location for each mask wear condition. * Indicates a significant difference compared to control conditions; ** Indicates a significant difference from control and SLR mask conditions.

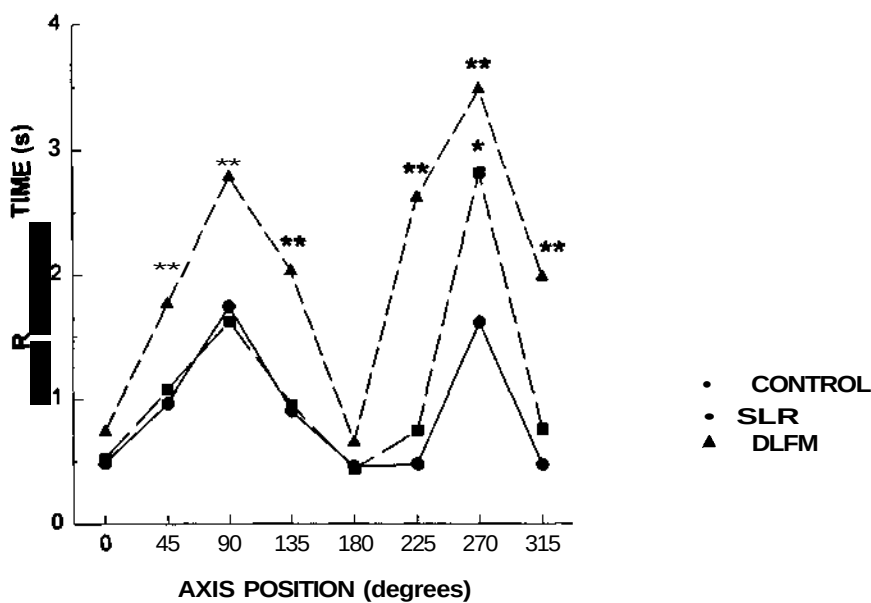


Figure 4. Group mean reaction times from each mask condition for the four stimuli on each of the eight field axis positions. * Indicates a significant difference compared to control conditions; ** Indicates a significant difference from control and SLR mask conditions.

mask from approximately 4.5 cm from the left face seal periphery to within 4.5 cm of the right face seal periphery. Other respirators with single lens designs similar to the SLR concept used in this study have shown similar results when compared to a dual eye-lens mask (McAlister and Buckingham, 1993). Thus, the differences observed between the SLR and DLFM conditions were not unexpected.

Unique to this investigation was the assessment of the pattern of impairment to performance within the visual field produced by the different mask configurations as measured with the signal detection perimeter. Peripheral LED rings (12°, 38°, 64°, and 90°) showed that mean response times for signal detection increased with greater peripheralization of the light signals for all test conditions. This general configuration of the data is comparable with the findings of previous research using this task (Kobrick and Dusek, 1970; Kobrick, 1974; Kobrick and Sleeper, 1986).

Impairments in signal detection time were significantly greater for the DLFM mask compared to control and SLR trials for stimulus rings 38°, 64°, and 90° from the center of the perimeter. Several factors may explain these observed differences between the SLR prototype respirator and the DLFM respirator. First, as evidenced by the differences in absolute contours of the field of view, the single eye-lens design of the SLR concept resulted in a larger field of view that enabled a greater number of peripheral light signals to be detected. Secondly, the face piece of the SLR concept used in this study was molded of a transparent silicone rubber whereas the DLFM mask was molded with opaque rubber materials. As expressed by a few of the study volunteers, the clear facepiece tended to reflect light signals that were not actually observed by the volunteer. Although instructed to respond only to stimuli that were seen, some volunteers perceived the light reflections as observed stimuli and responded accordingly. This effect appeared to be most evident for the most superior and peripheral light signal (rib zero, lamp 4). In addition, the fact that the SLR design did not

place a purifying filter element on the face-piece may have positively influenced the results. Based on the placement of the filter element on the DLFM mask, the filter itself was partially visible to the wearer through the left eye-piece, thus causing an additional obstruction for viewing in the lower left visual field. The very low visual field radial limit performance rating and relatively large standard error (Table 1) observed for the DLFM mask for the axis position of 210°, the position most obstructed by the filter, supports this conclusion.

The mean reaction times for the eight radial axes of the signal detection perimeter serve as an indication of the effect of the stimulus' general location in the overall visual field (Kobrick and Sleeper, 1986). Compared to the control condition, reaction time during mask wear was most impaired in the inferior (225° to 315°) visual field area. The prolonged reaction time means for the DLFM mask condition compared to control and SLR trials demonstrated that the general location of stimuli in the superior and inferior visual fields were significantly affected by wear of the DLFM respirator. Wear of the SLR concept mask was comparable to control measurements at all axis positions except the 270° axis position. This finding suggests that despite the visual field improvements that the SLR design provides to the user, stimuli located in the inferior central line of sight will continue to be difficult to observe in a timely manner. The longer reaction times observed for both mask wear conditions reflect the narrowing of inferior visual field observed for performance ratings of field of view limits. Again, the differences between the SLR and DLFM masks appear to be due to differences in lens design, location of the air-purifying filter, and facepiece material. As in previous research using the signal detection task, the least impairment in response time occurred along the horizontal axis of view, indicating that normal viewing during mask wear is most effective along the horizontal line of sight where most visual activity normally occurs (Kobrick and Sleeper, 1986).

Conclusions

Wear of both the DLFM and SLR full face-piece respirators used in this study caused overall visual field to be narrowed. However, the performance decrements were most dramatic for the DLFM respirator. The visual detection sensitivity task used in this study showed that reaction time for detection

of light signals increased with greater peripheralization of the stimulus and that the best performance occurred for light located along the horizontal axis of view. Wear of the DLFM mask resulted in the greatest impairments to this response configuration. In contrast, signal detection reaction times were

almost identical between control and SLR mask conditions. From a military stand-point, considering the importance of visual field capability for the bulk of military tasks, pursuit of respirator designs using single lens pieces and remotely mounted air-

purifying canisters seems to be warranted. Smaller diameter, lower profile canisters should also be considered. Likewise, operational effectiveness in industrial settings that require full face-piece respirator wear could also benefit from such a design.

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