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Visual Performance of Contact Lens-Corrected Ametropic Aviators with the M-43 Protective Mask

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The present study investigated the use of extended wear soft contact lenses with the Apache aviator's M-43 protective mask. Visual functions tests (high and low contrast visual acuity, contrast sensitivity, color vision), visually-based cognitive tests, and user-comfort questionnaires were employed with normally sighted aviators and with aviators fitted with hydrogel soft contact lenses. Tests were administered shortly before donning the mask, immediately after donning the mask, and at hourly intervals, over the course of the next four hours of continuous mask wear. Physiological function (tear break-up time, tear production, slit lamp examination) was assessed before donning the mask and directly after its removal. The results of the study indicated, for some subjects in both groups, the presence of subjective discomfort (from the M-43's airflow around the eyes) and mildly increased conjunctival injection ("redness"). However, no significant changes in visual

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function, cognitive performance, or physiological function were observed in either group as a result of wearing the mask. These data confirm previous work indicating acceptable visual performance with the M-43 mask and indicate that extended wear soft contact lenses can be worn with the M-43 protective mask without degrading selected aspects of visual performance.

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SGT Vincent Reynoso conducted many of the physiological tests, SSG Nonilon Fallaria administered autorefractions, and Mr. Simon Grase coordinated subject movement through each test station and assisted in data reduction. SGT Terry Wright, U. S. Army Aviation Center, Directorate of Training and Doctrine, Fort Rucker, Alabama, provided expert help with mask fitting. To each of these individuals we are extremely grateful. We especially thank Dr. John Crosley for obtaining the masks and for providing his professional advice and his consultative support.

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Table of contents

Appendixes

List of figures

List of tables

Introduction

The AH-64 Apache is the U.S. Army's most current attack helicopter and its most advanced rotary-wing aircraft to date. It is the Army's first helicopter designed specifically to operate under adverse weather conditions, both day and night. Its ability to fight, survive, and win depends heavily on its advanced display and weapons systems technology and its deft maneuverability over rugged terrain. Essential to its mission capability is its reliance upon a high degree of man-machine integration.

The principal component of the Apache's advanced display interface is the Helmet Display Unit (HDU). A component of the AH-64's Integrated Helmet and Display Sighting System (IHADSS), the HDU consists of a miniature cathode ray tube (CRT) located at the end of an optical relay tube attached to the side of the aviator's helmet (Figure 1). A beamsplitter (the "combiner"),

Figure 1. Pilot wearing Apache aviator's helmet with attached Helmet Display Unit (HDU).

located at the eye position, reflects the CRT's imagery into the pilot's right eye. The imagery presented to the pilot consists of a video mix of both flight and weapons control symbology and, from forward-looking infrared sensors mounted on the nose of the aircraft, a representation of the world outside.

The HDU is designed to provide the pilot with a 30 degree (vertical) by 40 degree (horizontal) monocular field-of-view. However, in order to attain full-field viewing, the pilot must properly position the HDU against his right cheek and precisely angle the combiner in front of his right eye. While the non-corrective lens wearing (emmetropic) aviator can accommodate the HDU's short physical eye relief distance, his spectacle wearing (ametropic) counterpart often cannot. To maximize the spectacle wearer's view, modifications must be made to the frame and right eyelens of his standard aviator spectacle (McLean and Rash, 1984). However, even with modified spectacles, many ametropic Apache aviators (and many emmetropes wearing spectacle laser protection) still experience difficulty in seeing critical flight and weapons symbology along the periphery of the CRT (Behar et al., 1990).

The physical constraints imposed by the HDU impact yet another aspect of system compatibility -- the AH-64 aviator (emmetrope or ametrope) no longer can wear his standard issue (M-24) aviator's mask for respiratory protection. In response, the Army is developing a new mask, designated as the M-43, to provide Apache (and subsequently, all Army) aviators with protection against nuclear, biological, and chemical threats.

The M-43 protective mask consists of a full-face bromobutyl/rubber molded faceblank with molded polycarbonate lenses that conform closely to the shape of the eyes (Figure 2). The right lens of the mask is notched to facilitate proper positioning of the HDU. A series of sized interpupillary distance (IPD) staples is used to adjust the lenses for proper optical centering. Although alleviating the emmetrope's HDU-mask interface problem, the form-fit design of the M-43 creates a new dilemma for the ametrope as it precludes his wearing standard protective mask optical correction (spectacle or insert) under his protective mask.

Initially, it was expected the M-43's optical correction could be furnished either as a supplementary lens bonded directly onto the mask's eyepiece ("glue-ons") or worn in a frame attached to the mask's outside ("frontserts"). However, the glue-on's inherently high radius of curvature can produce unwanted magnification and distortion effects (Crosley and Rash, 1990) and the increased thickness of additional optical elements from either glue-ons or frontserts will increase the HDU's vertex distance and reduce the observer's field-of-view (Davis and

Smith, 1989). (Davis and Smith also report that glue-ons in the cockpit impair binocular vision and the notch in the right eyepiece can produce viewing distortions.) Because of these intrinsic design problems, neither corrective lens option has as yet received medical department or user approval.

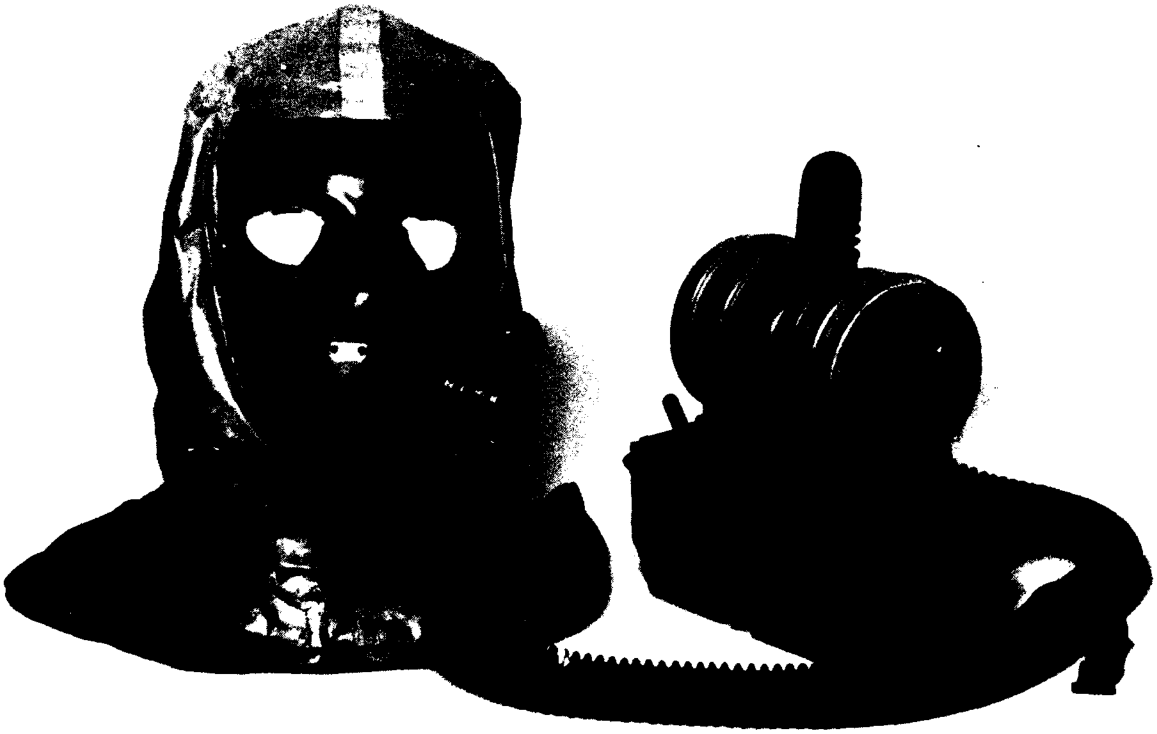

Figure 2. M-43 Apache aviator's protective mask. The right eyelens is notched to facilitate HDU placement. The blower (lower right), attached to the mask via the blower tube, provides air into the mask for cooling and eyelens defogging.

Contact lenses. An alternative means of refractive error correction is the use of contact lenses. As Crosley, Braun, and Bailey (1974) point out, compared to spectacles, contact lenses offer numerous advantages to the military ametrope, including increased visual field, reduced fogging, and instant compatibility with sighting devices and protective masks. However, early work with hard plastic lenses showed that user comfort could be compromised by dust or foreign bodies trapped under the lens or by corneal edema arising from the lens' lack of oxygen permeability. Worse yet, under dynamic conditions, small, hard lenses could dislodge or become lost. Because of these and other potential lens-related impairments to vision and, putatively, to flight safety, contact lenses were denied for use in Army aviation.

In 1974, Crosley, Braun, and Bailey demonstrated ametropic Army aviators could wear soft hydrophilic contact lenses successfully in the flight environment. However, because of reported acuity fluctuations and difficulty in maintaining adequate lens hygiene in the field, the unconditional use of soft lenses could not be endorsed. Polishuk and Raz (1975) reached similar conclusions following work with Israeli pilots. With continued improvement in both material and fitting technique, subsequent workers, both here and abroad, have reported good wearing characteristics and successful flying performance with soft contact lenses (e.g., Bachman, 1988; Brennan and Girvin, 1985; Tredici and Flynn, 1987) and the use of contact lenses in civil aviation is now quite common (Dille and Booze, 1980; 1982). In addition, recent tests have shown current generation soft contact lenses can be worn successfully by ground troops, even in the field (Van Norren, 1984; TRADOC Combined Arms Test Activity, 1986; Rouwen and Rosenbrand, 1986; Bachman et al., 1987).

Current contact lens-related research in Army aviation is focused on examining user acceptability, operational performance, and health risks associated with the use of extended-wear soft contact lenses (Bachman, 1988; Lattimore, 1988; Lattimore and Cornum, 1989; see Hill, 1988, for work with Air Force tactical air crews). Part of this assessment requires investigating the visual performance of lens corrected ametropes in the M-43 mask. Assuming that satisfactory user comfort and refractive error correction can be achieved, the visual performance of extended-wear soft lens wearers should be comparable with that observed in earlier tests with mask-wearing emmetropes. (For example, using standard clinical procedures with emmetropic M-43-masked observers, Rash et al. [1984] and Walsh, Rash, and Behar [1987] showed no degradation in either high contrast acuity or contrast sensitivity, providing the mask was functioning normally. Eyepiece fogging resulting from a malfunctioning mask blower [see below] degraded both visual acuity and contrast sensitivity for middle and high spatial frequencies.) However, because of a unique design feature within the M-43 ensemble, namely its cooling system, concern exists with respect both to the integrity of the soft contact lens and the visual performance of lens-corrected pilots.

The M-43's cooling system includes an external portable blower, attached to the mask by a hose, which provides the mask with filtered air at ambient temperature (Figure 2). Separate ducts under the mask distribute the air to various locations around the wearer's head -- under the hood for user comfort, over the inside surface of the lenses for lens defogging, and into the body of the mask for breathing assistance. A control knob on the blower and individual inlet valves on the side of the mask regulate the airflow to the air distribution systems. A flow control outlet, located under the voice emitter, adjusts the positive pressure without interfering with normal respiration. Maximum airflow into the mask is reported to be about 4.0 ft per minute.

Soft contact lenses require sufficient hydration (from the lenses and from tear flow) to maintain a stable index of refraction and adequate oxygen transmissivity for normal corneal function. Thus, factors which encourage or enhance hydrogel lens and ocular surface drying, such as low humidity or persistent airflow around the eyes, could impair the effective power, fitting characteristics, and oxygen permeability of the lens (Andrasko and Schoessler, 1980). Over several hours of exposure, corneal physiology, wearer comfort, and visual performance could be degraded (Carboy, 1980).

The present study was conducted to assess and compare several aspects of aviator visual performance with the M-43 mask. Visual function tests, visually-based cognitive tests, and user-comfort questionnaires were employed with emmetropes and with ametropes fitted with hydrophilic extended-wear soft contact lenses. Tests were administered shortly before donning the mask, immediately after donning the mask, and, at hourly intervals, over the course of the next 4 hours of continuous wear. Physiological function and corneal integrity also were assessed before donning the mask and directly after its removal. The interpretation of the results is made with respect to the medical standards for vision contained in Army Regulation 40-501.

Methods

Subjects: Eleven male volunteers (22 eyes) were divided into two groups. Six emmetropes (three AH-64 Apache pilots and three initial entry rotary wing students) served as a noncontact lens (NCL) wearing control group to assess normal visual performance with the M-43 protective mask. Five contact lens-wearing AH-64 pilots, participating concurrently in another contact lens study (Lattimore, 1988), served as the contact lens (CL) experimental group. An additional AH-64 Apache aviator, with only right eye contact lens correction, also was tested. All subjects met current Army visual medical standards for aviators and were on active flight status. Appendix A contains each subject's age, refractive status (unaided), and for lens wearers, wearing experience and lens power.

Contact lenses and wearing regime: CL subjects were fitted with Vistakon* Acuvue™ disposable soft (hydrogel) contact lenses having a nominal water content of 58 percent. Base curves and diameters for all the lenses measured 8.8 and 14.0 mm, respec-

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* See Appendix G.

tively. All the lens wearers were considered "successful fits," having from 2-9 months of uninterrupted lens wearing experience. All were maintained on a modified extended wear schedule consisting of a maximum of 6 consecutive days of wear followed by an overnight of "rest" (i.e., without wear).

M-43 protective mask: M-43 protective masks were provided by the U.S. Army Chemical Research Development and Engineering Center (CRDEC), Aberdeen Proving Ground, Maryland. The masks were sized from small to extra large and included a graded series of IPD staples for optical centering. Masks were fitted individually by a aviation life support equipment specialist trained expressly for this task by CRDEC. Throughout the course of testing, the subject carried the blower (ground version) at his side using the harness assembly supplied with the mask. The blower's air flow control was set and the air distribution valves were adjusted to maximize airflow across the eyepieces (and contact lenses) -- a "worse case" condition. Blower fan batteries were replaced midway during the test session, i.e., after about 2 hours of use. During this procedure, the subject held his breath for a few seconds to avoid fogging the lenses. Once donned, the mask was worn continuously for the duration of testing, a period of about 4.5 hours.

Physiological measures: Slit lamp examinations were conducted to assess both corneal integrity and physiological stress. Clinical evaluations were made for conjunctival injection, fluorescein staining, lens fit, and tear break-up time (BUT). Injection and staining were graded subjectively on a 0-4 scale (0=none, 4=severe) and classified according to either location (injection) or type (staining: abrasion, punctate, etc.). In addition to the physiological estimates, corneal thickness was measured with a Teknar* ultrasound pachometer, tear production was determined by the Schirmer tear test (under topical anesthesia), and CL water content was measured using an Arizona Instruments* evaporometer. (In the latter procedure, the subject's two lenses were inserted into the evaporometer and the average percent water content calculated using the lens pair. Only the single lens was used for the subject corrected monocularly.)

Vision tests: High and low contrast visual acuities (HCVA, LCVA) were obtained using the Bailey-Lovie Visual Acuity Charts (Nos. 4, 5, 6, and 7), contrast sensitivity (CS) was assessed with the Pelli-Robson Letter Sensitivity Charts (Nos. 2K and 4K, Serial No. 89K), and color vision was evaluated using the Lanthony Desaturated D-15 test. The tests are described in Appendix B. Visual histories were obtained and refractive error measurements were made as needed.

All the visual function tests were administered monocularly and consistent with recommended procedure (Bailey and Lovie, 1976; Pelli, Robson, and Wilkins, 1988; Lanthony, 1978). Viewing

1976; Pelli, Robson, and Wilkins, 1988; Lanthony, 1978). Viewing distances for the VA and CS charts measured 20 and 10 feet, respectively. Illumination was provided by a combination of ceiling- and stand-mounted fluorescent lamps that provided fairly even lighting of about 1636 lux (Figure 3). Background luminance of the Bailey-Lovie charts averaged 411 cd/m^2, while for the Pelli-Robson charts it measured 453 cd/m^2. The Lanthony color vision test was administered in a separate room that was dimmed except for a 100 watt Macbeth daylight lamp over the test work-space; the subjects determined their own viewing distance (Figure 4.)

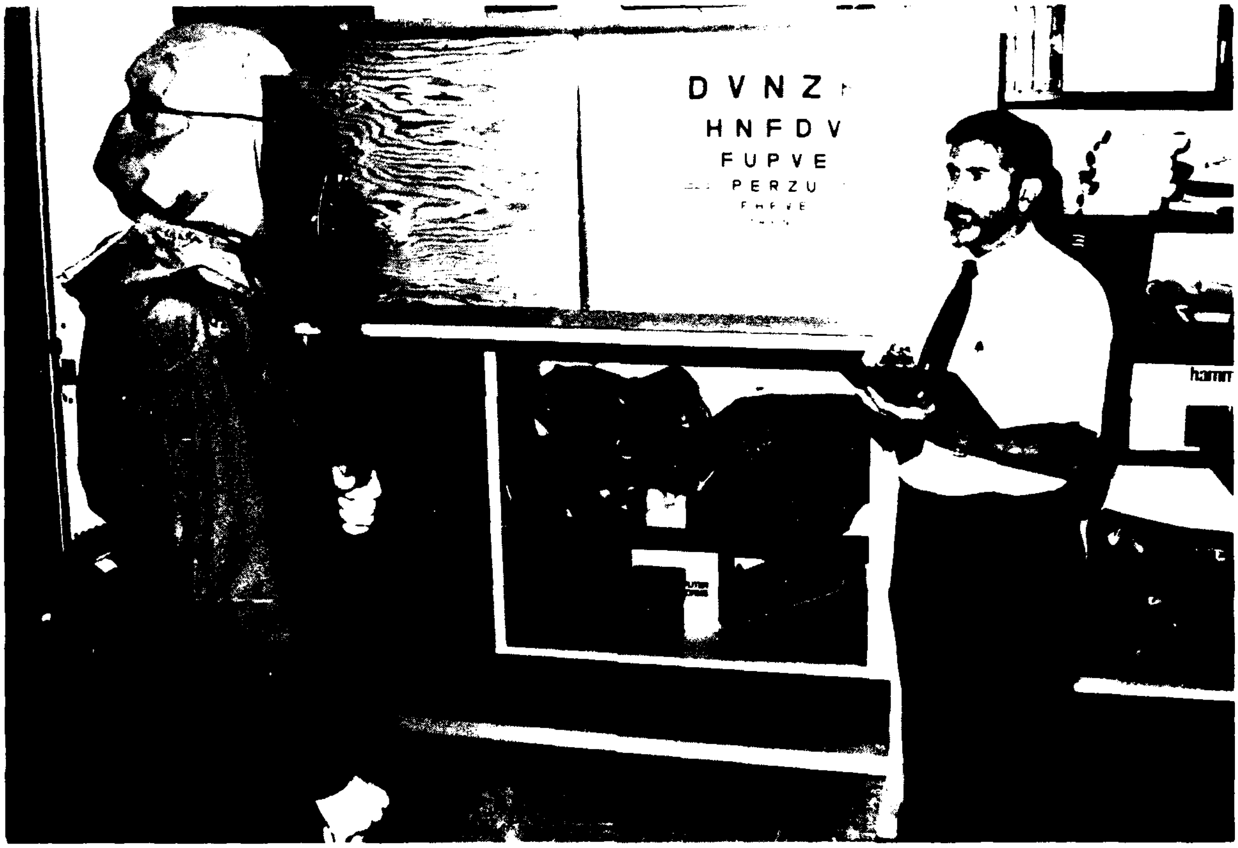

Figure 3. Administration of the Bailey-Lovie high contrast visual acuity test to the subject's left eye. (The distance between subject and test chart has been reduced for photographic presentation.) Also shown, but partially hidden by the subject, are the blower and one of the two fluorescent floor lamps (to the left of the subject).

Figure 4. Masked subject taking the Lanthony D-15 color vision test.

To facilitate data collection, the tests were arranged in a minibattery and presented sequentially as follows: HCVA -- right eye, LCVA -- right eye; HCVA -- left eye, LCVA -- left eye; CS -- right eye, CS -- left eye; color vision -- right eye, color vision -- left eye. To reduce familiarity with the VA and CS tests, a different, although nominally equivalent, version of each test chart was used with each eye. Each subject received identical eye/test chart pairings

Cognitive tests: Three tests from the psychological assessment battery (PAB) were used to evaluate the effects of the experimental conditions on visually-based cognitive performance. The tests, adapted from the unified tri-services cognitive performance assessment battery (Perez et al., 1987), were presented on a specially designed hand-held computer developed by Paravant Computer Systems. The computer had an alphanumeric keypad and a high contrast supertwist liquid crystal display screen measuring 2.75 inches vertically X 5.00 inches horizontally (Figure 5). The tests are described below; sample screens are shown in Appendix C.

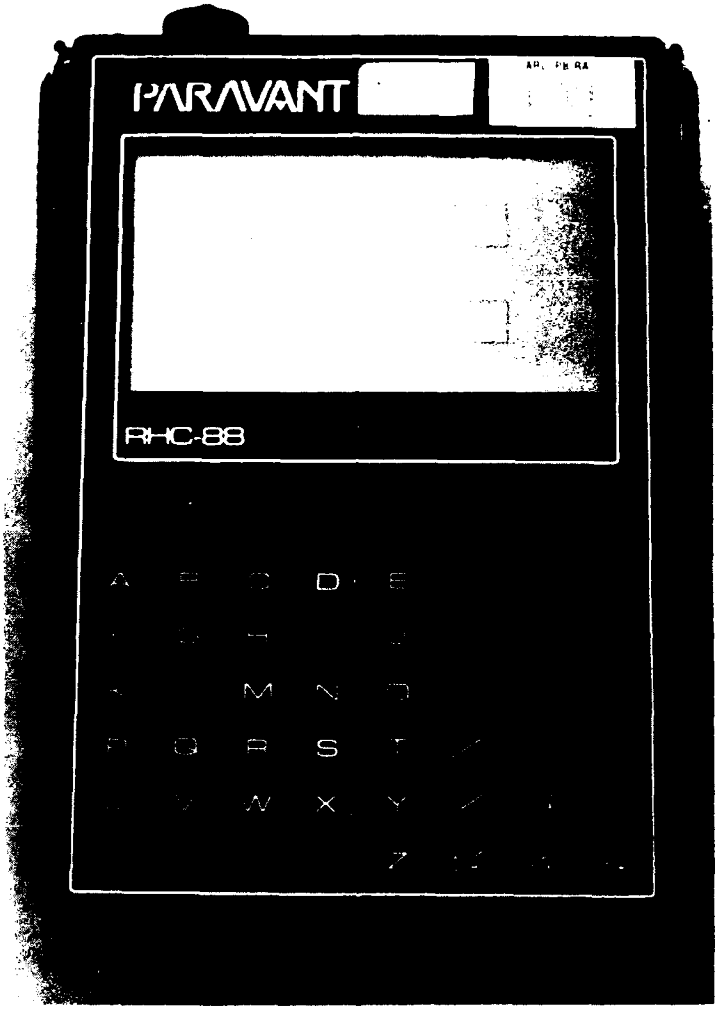

Figure 5. Hand-held computer for cognitive test presentation. The "S" and "D" keys were used to indicate responses of "yes" and "no" or "same" and "different." The "1," "3," "7," and "9" keys on the numeric keypad are used to indicate object positions on the four-alternative serial reaction time task (see text).

The <u>MAST-6</u>, a test of perceptual speed, required subjects to search for and detect targets embedded in a linear array of nontarget items. Targets consisted of a row of six letters presented at the top of the screen; subjects determined whether the letters were contained, in any order, in a row of 20 letters at the bottom. A total of 10 trials were presented over a 3-minute period. Subjects indicated their response ("yes"/"no") by pressing one of two assigned keys. Response latency and the number of correct responses served as the primary performance measures.

The Matrix-1 tested short-term spatial memory. In this task, a pair of "patterns" were shown on the screen, each pattern consisting of an abstract array of 14 asterisk characters. The second pattern could be identical to the first or differ by having three of its asterisks displaced; however, it was always separated temporally from the first by a brief (< 1-sec) delay. Subjects indicated their response ("same"/"different") by pressing one of two assigned response keys. A total of 30 trials were given over a 3-minute period; response latency and the number of correct responses served as primary measures of performance.

The Wilkinson test determined the subjects' latency to detect and indicate positional change. Four boxes - three empty and one filled -- appeared near each corner of the screen. The filled box could remain in place or change location from trial-to-trial. The subjects' task on each trial consisted of pressing one of four assigned keys corresponding to the location of the darkened box (a four-choice serial reaction time task). Subjects were presented with a maximum of 100 trials over a period of 3 minutes; response latency served as the principal measure of performance.

The three PAB tests, organized into a minibattery, were presented in fixed order (MAST-6, Matrix-1, and Wilkinson). The specific items within each test varied from one battery to the next; however, all the subjects received identical tests. Subjects were tested binocularly under normal roomlight; they also determined their own viewing distances. Performance feedback was provided by the computer after each trial; summary feedback was also computer-provided at the end of each test.

Questionnaire: A short questionnaire was used to measure various aspects of ocular comfort/discomfort (e.g., eye irritation, eye dryness, etc.) and visual quality (e.g., fogged/hazy vision, glare effects, etc.). Responses to each of these questions were made on a graded subjective scale that varied from 0 ("not at all") to 4 ("severe"). Subjects also were asked to compare visual performance with and without the mask and the CL group was asked to assess the prevailing comfort of their contact lenses. Responses to these latter questions were rated on a scale ranging from +2.0 ("much better with the mask"; "very comfortable") to -2.0 ("much worse with the mask"; "very uncomfortable"). The questionnaire is shown in Appendix D.

Procedures: Subjects participated over 2 consecutive days. On day-1 (training day), subjects were briefed on the nature of the study and asked to provide their informed consent. Visual histories and manifest refractions then were obtained as needed. Subjects were then given 2 hours of PAB practice using a training protocol (six administrations of the battery, each separated by 10 minutes of rest) known to produce stable and asymptotic levels of performance (Stephens, 1989). At the conclusion of training, lens wearers were instructed to insert new lenses before retiring for the night.

Day-2's (test day) activities were divided into separate test periods (Table 1). The first period (premasking phase) was used to establish baseline, nonmask performance by presenting the subjects with their initial exposure to the visual and cognitive tests and the questionnaire. This was followed by physiological testing during which the lens wearers also surrendered their

Table 1.

Test day (day-2) schedule

Phases:	Premask	Hour-0	Hours 1-4	Postmask
Mask:	No mask worn	Mask fit and worn	Mask worn continuously	No mask worn
CL Group	1. Vision tests -------	>	----------->	
	2. Cognitive tests ----	>	----------->	
	3. Questionnaire ------	>	----------->	
	4. Physiological tests	---------	-------------	------>
	5. Lenses surrendered for water content measurement (new lenses issued)	---------	-------------	------>
				6. Exit debriefing
NCL Group	1. Vision tests -------	>	----------->	
	2. Cognitive tests ----	>	----------->	
	3. Questionnaire ------	>	----------->	
	4. Physiological tests	---------	-------------	------>
				5. Exit debriefing

lenses for water content measurement. At the end of this procedure, CL wearers were issued replacement lenses and, following their insertion, permitted an additional few minutes for visual and physiological adaptation before resuming testing.

In the next period (hour-0), the mask was fit, its airflow adjusted, and the subjects permitted a few moments to adapt to its wear. The test series (excluding physiological testing) then was promptly repeated with subjects now masked. Using the time at the onset of donning to denote the beginning of mask wear, this test series was repeated every 60 minutes for the next 4 hours (postdonning hours 1-4). Each iteration of testing lasted about 30 minutes; between iterations, the subjects could read or watch television.

At the end of the last series of tests, subjects removed their masks and underwent a second and final (postmask) series of physiological tests. CL subjects once again submitted their lenses for water content analysis and were provided with a replacement pair. Testing for all subjects terminated with an exit debriefing. The flow of events over the 2 days of testing are shown in Appendix E. Except for the procedures and measurements associated with the contact lenses, both groups were treated exactly alike.

<u>Data analysis</u>: The data were analyzed to determine performance changes as a function of both the mask's optical quality(ies) and sustained exposure to its airflow. Because differences in shape between left and right eyepieces (no-notch vs. notch) ostensibly could produce local turbulence conditions around the eyes, independent ocular effects (left vs. right eye), were assumed. Effects resulting from degraded optical quality were measured in each group by comparing premask and hour-0 performance, i.e., performance just before and after donning the mask. Cumulative effects (i.e., effects due to continuous mask wear) were determined by examining performance changes over the entire wearing period, hours 0-4. Effects of mask wear specific to CL use were determined by comparing CL and NCL performance.

Visual functions test data. Separate mixed-factor analyses of variance (ANOVAs) were used to determine both immediate and cumulative mask effects for each test of visual function. Eye (left/right) and test phase (Premask/hour-0 or hours 0-4) were treated as repeated measures variables; group (CL/NCL) served as the grouping variable. The base-10 logarithms of the minimum angle of resolution (logMAR) and the reciprocal of the contrast threshold served, respectively, as principal dependent variables for VA and CS. Error score was used as the dependent measure for the Lanthony color vision test. Data from the unilaterally corrected CL subject were omitted from these analyses; statistical significance was determined at the .05 level.

Cognitive test data. A failure in one of the hand-held computers resulted in the loss of data for three of the six NCL subjects. Therefore, statistical analyses were limited to data from the CL group. (Cognitive data from the three remaining non-lens wearers are presented graphically). Differences between CL group's premask and hour-0 performance were determined by paired t-tests for each cognitive test. The effects of sustained wearing were tested with individual single factor (test phase: hours 0-4) repeated measures ANOVAs. Response latency served as the primary dependent variable in each of the analyses.

Physiological tests and questionnaire. Pre/post differences in corneal thickness, tear BUT, and tear production (Schirmer tear test) were assessed by separate mixed factor ANOVAs. For each ANOVA, test phase (premask/postmask) served as the repeated measures variable and Group (CL/NCL) served as the grouping factor. A paired t-test was used to evaluate pre/post differences in water content among the lenses submitted by the CL group. Responses to the questionnaire were inspected for trends associated with both immediate and cumulative effects of mask wear; the results are presented descriptively.

Results

Visual function tests. The test results for acuity and contrast sensitivity are summarized in Figures 6-8. (No significant effects were found for color vision.) For acuity, treatment means (thick bars) are presented in terms of both minimum angle of resolution (smallest resolvable letter target) and its Snellen equivalent; CS means are expressed in terms of log contrast sensitivity. Standard deviations are represented by the thin vertical bar atop the means and are displayed unidirectionally for clarity of presentation. To facilitate comparison, data from each of the periods are shown together.

As can be seen, visual performance within each of the groups was fairly consistent over the course of testing. Acuities in both groups ranged from 20/12-20/20 on HCVA and from 20/15-20/30 on LCVA. Contrast thresholds (log contrast sensitivity) ranged from 1.62 to 2.08. Significant differences were detected between the groups on HCVA across Hours 0-4 (Figure 6). Group differences were also observed for CS during the premask and hour-0 phases (Figure 8). In both cases, measured visual performance was slightly better in the NCL than in the CL group, independent of mask wear. (Similar results for CS have been reported previously by others [Applegate and Massof, 1975; Woo and Hess, 1979; Mitra and Lamberts, 1981; Grey, 1986; but see Bernstein and Brodrick, 1981; Dennis et al., 1988, for contradictory findings]). However, while differences between the groups were noted in both HCVA and CS, as shown in Figures 6 and 8, the actual differences in both tests were small (e.g., in HCVA, 1-3 letters or

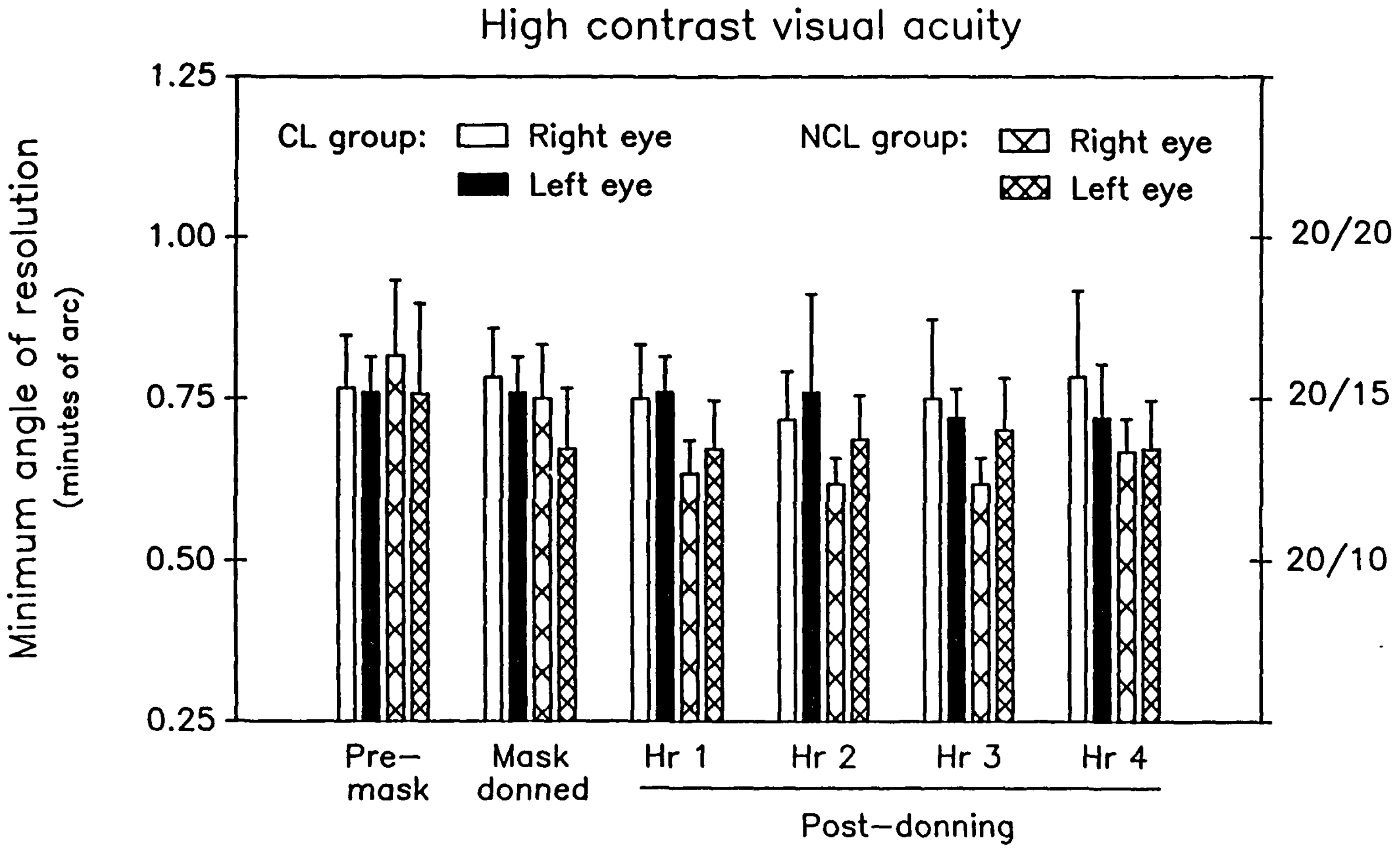

Figure 6. High contrast visual acuities among contact lens and noncontact lens wearer across all test phases. Means for each eye shown by thick bars; +1 standard deviations are shown by thin bars atop the means. Acuities are expressed in terms of minimum angle of resolution (left axis) and their Snellen equivalents (right axis). Better acuities (finer resolving capability and lower Snellen scores) are represented by shorter bars.

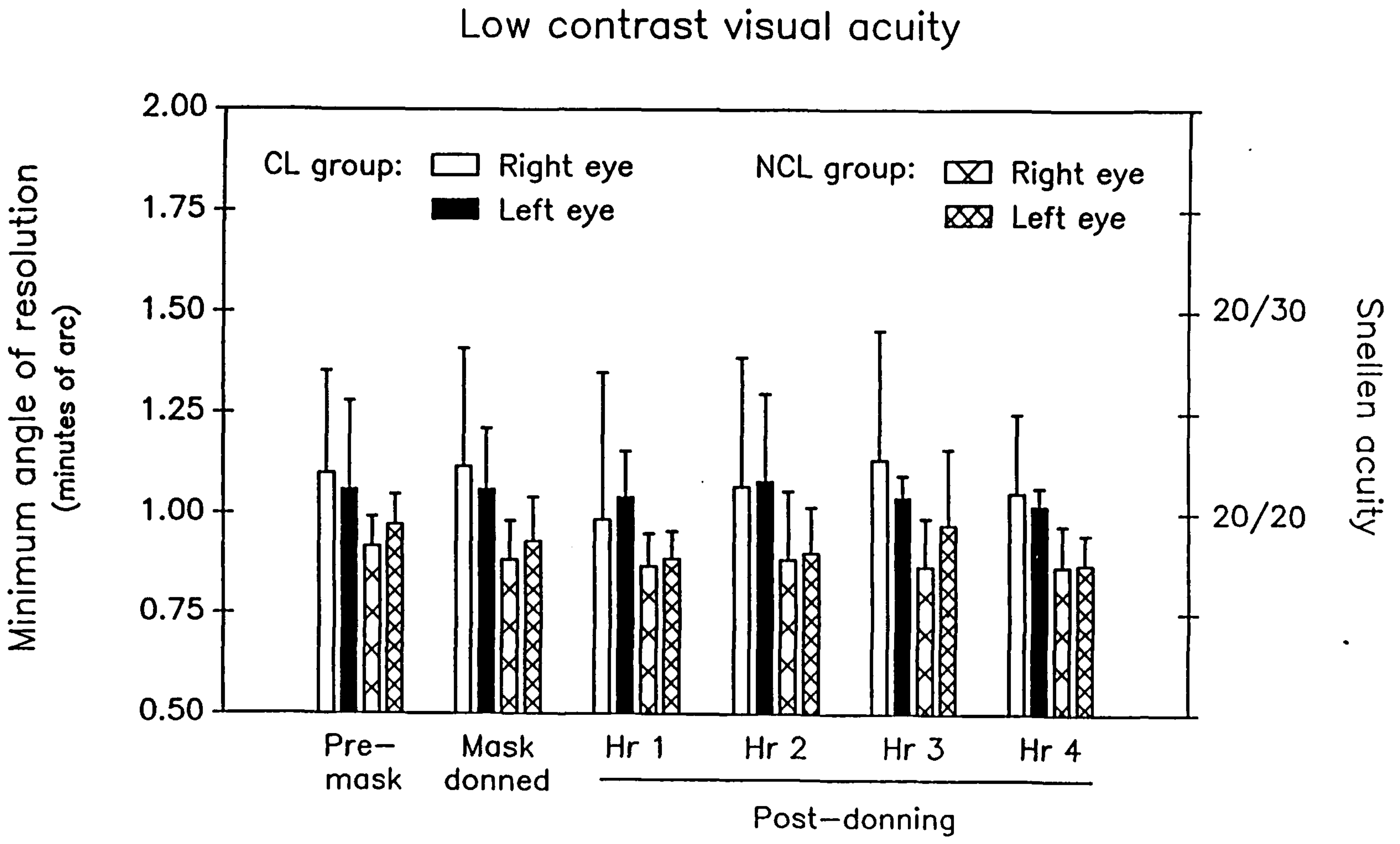

Figure 7. Low contrast visual acuities among contact lens and noncontact lens wearers across all test phases. Interpretation of the figure is similar to that of Figure 6.

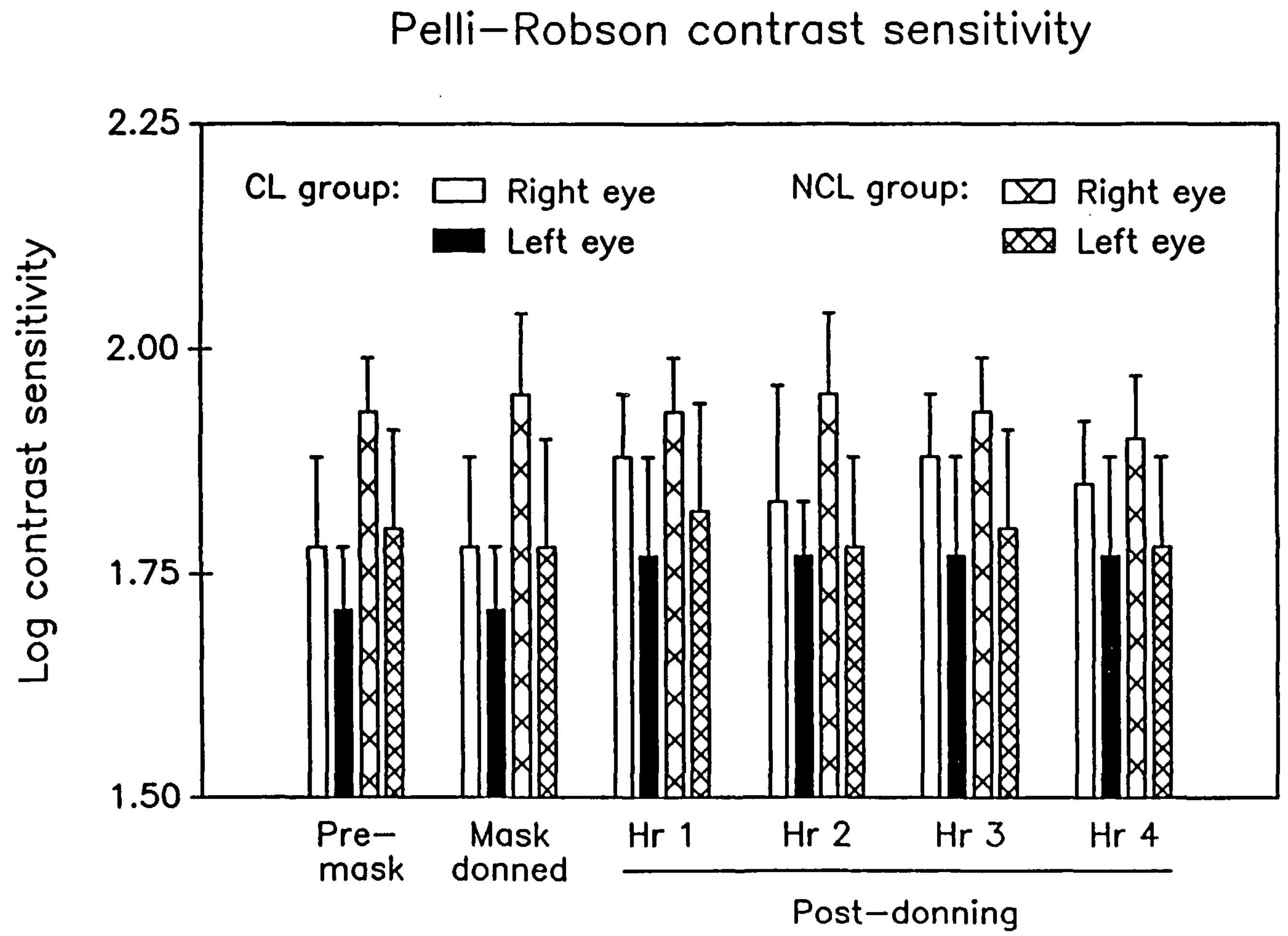

Figure 8. Contrast sensitivity thresholds for both groups at each test phase. Means and standard deviations are represented as in the previous two figures. In this figure, better sensitivity is represented by higher bars.

a fraction of a Snellen line) -- perhaps too small to merit practical significance. Even more important, from the point of view of the present study, analyses of the data revealed no significant period main effects or period X group interactions indicating, in both groups, an absence of immediate or progressive impairment(s) in visual function as a result of wearing the M-43 mask.

Cognitive tests. As measured by response rate, latency, or number of correct responses, M-43 mask wear had negligible effects on cognitive test performance. At each phase, response rates on each test were nearly 100 percent. In addition, while numbers of correct response generally were test specific, both the CL and NCL subjects exhibited similar correct response rates on each test. These data are shown in Table 2. Figure 9 presents numbers of correct recognitions in the Matrix-1 test for both groups across each test phase.

Latency "profiles" for each of the tests are presented in Figures 10-12. As in the previous figure, solid lines connect the CL group's mean reaction time across each phase of testing; surrounding dotted lines connect each mean's +1 standard deviation. Filled circles represent average response latencies for the three NCL subjects from whom cognitive test data were available. As can be seen, reaction times on each of the tests were generally consistent across all test phases. (CL MAST-6 latencies [Figure 10] displayed a transient increase during hour-3 of about 50 msec with response times returning to baseline levels by hour-4 [an effect likely due to boredom, fatigue, or small sample size]). Although based on a limited subject sample, average NCL latencies typically fell near or within the "performance envelope" generated by the CL group (the slightly elevated reaction times on the MAST-6 test resulting from the longer test-day reaction times of a single NCL subject). In general, the analyses of cognitive test data failed to offer any compelling evidence for a mask-related decrement in visually-based cognitive performance.

Clinical impressions: Cornea. Four of the 11 contact lens-wearing eyes exhibited minimal or grade 1 punctate staining on the initial examination, while 3 of the 13 control eyes exhibited a similar level of fluorescein staining. All other eyes were judged to be clear, or free of staining. The number of eyes exhibiting baseline staining seemed to be an unusually high finding for both groups; pollen-based allergies were judged to be possibly contributing factors. After more than 4 hours of protective mask wear, the prevalence and degree of minor corneal punctate staining (grade 2 or less) increased for both the CL and NCL groups, with the left eye being somewhat more susceptible to fluorescein stain uptake than the right. There were no indications of corneal staining greater than grade 2 in either test group. Therefore, while there are some indicators of minor mask-

Table 2

Cognitive tests: Number/percent completed and correct*

MAST-6 test**

	Premask		Hour-0		Hour-1		Hour-2		Hour-3		Hour-4	
	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL
No. complete	10	10	10	9.7	10	10	10	10	10	10	10	10
% complete	100	100	100	97	100	100	100	100	100	100	100	100
No. correct	9.7	10	9.8	9.7	9.5	9.7	9.5	9.3	9.8	10	9.6	10
% correct	97	100	98	97	95	97	95	93	98	100	96	100

Matrix-1 test**

	Premask		Hour-0		Hour-1		Hour-2		Hour-3		Hour-4	
	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL
No. complete	29	29	30	30	30	29	30	29	30	30	30	30
% complete	97	97	100	100	100	97	100	97	100	100	100	100
No. correct	25	26	25	22	26	25	24	25	25	26	25	28
% correct	83	87	83	73	87	83	80	83	83	87	83	93

Wilkinson test**

	Premask		Hour-0		Hour-1		Hour-2		Hour-3		Hour-4	
	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL	CL	NCL
No. complete	100	100	100	100	100	100	100	100	100	100	100	100
% complete	100	100	100	100	100	100	100	100	100	100	100	100
No. correct	99	100	98	99	100	97	98	100	99	99	98	100
% correct	99	100	98	99	100	97	98	100	99	99	98	100

* CL group -- N=6; NCL group -- N=3

** All values are expressed to the nearest whole number

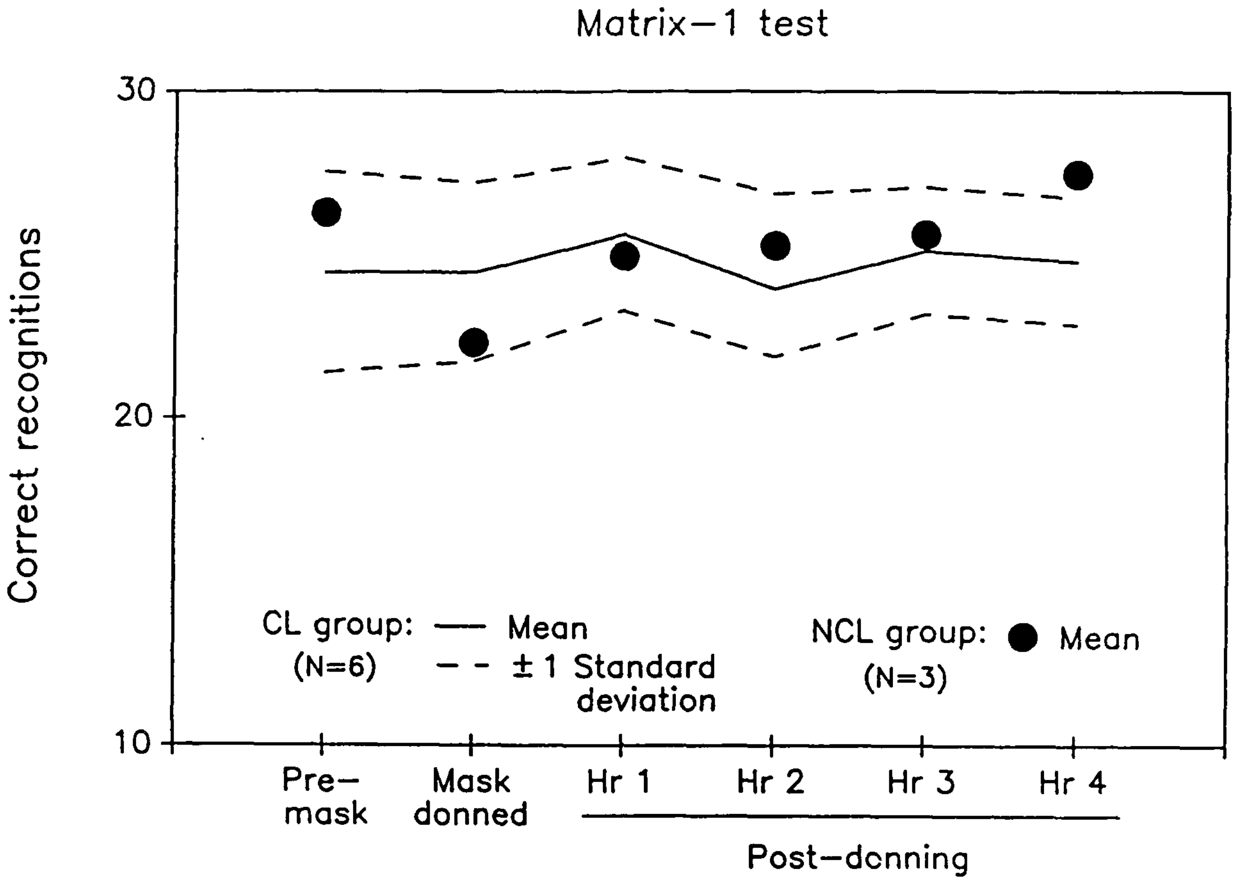

Figure 9. Number of correct recognitions on the Matrix-1 test for CL and NCL subjects at each phase of testing. Subjects were required to indicate whether two temporally separated abstract figures were the same or different. Solid lines connect the CL group's mean reaction time across each phase of testing; surrounding dotted lines connect each mean's +1 standard deviation.

group. Therefore, while there are some indicators of minor mask-induced corneal surface disruption, this process neither differentiates hydrogel lens wearers from nonlens wearers nor poses a threat to visual function.

Clinical impressions: Bulbar conjunctiva. All 24 eyes exhibited a minimal or grade 1 superficial injection of the bulbar conjunctiva on the initial, premask examination. While over half the eyes reacted to mask wear with mildly increased bulbar conjunctival injection, there was no clear difference between lens-wearing and nonlens wearing eyes. Since conjunctival injection also can be an indicator of corneal surface disruption, these data support inferences made from the corneal assessment data (i.e., minor irritative processes did not interfere with visual function).

Physiological measures. Baseline differences between the two groups were observed for both tear production and tear BUT. However, as shown in Table 3, tear production, BUT, and corneal thickness all displayed nonsystematic postmask effects relative to their premask levels. Depending on the measure, subjects in either group exhibited bilateral increases, decreases, or no change at all. In some cases, changes in opposite directions occurred in the two eyes simultaneously. Analyses of the corneal thickness data yielded small but significant differences between left and right eyes (left eye mean: 0.577 mm; right eye mean: 0.543 mm; df=1,1; F=15.36; p<.01). This difference was present in both subject groups before and after testing. Procedural review suggested these results may have been produced by a bias

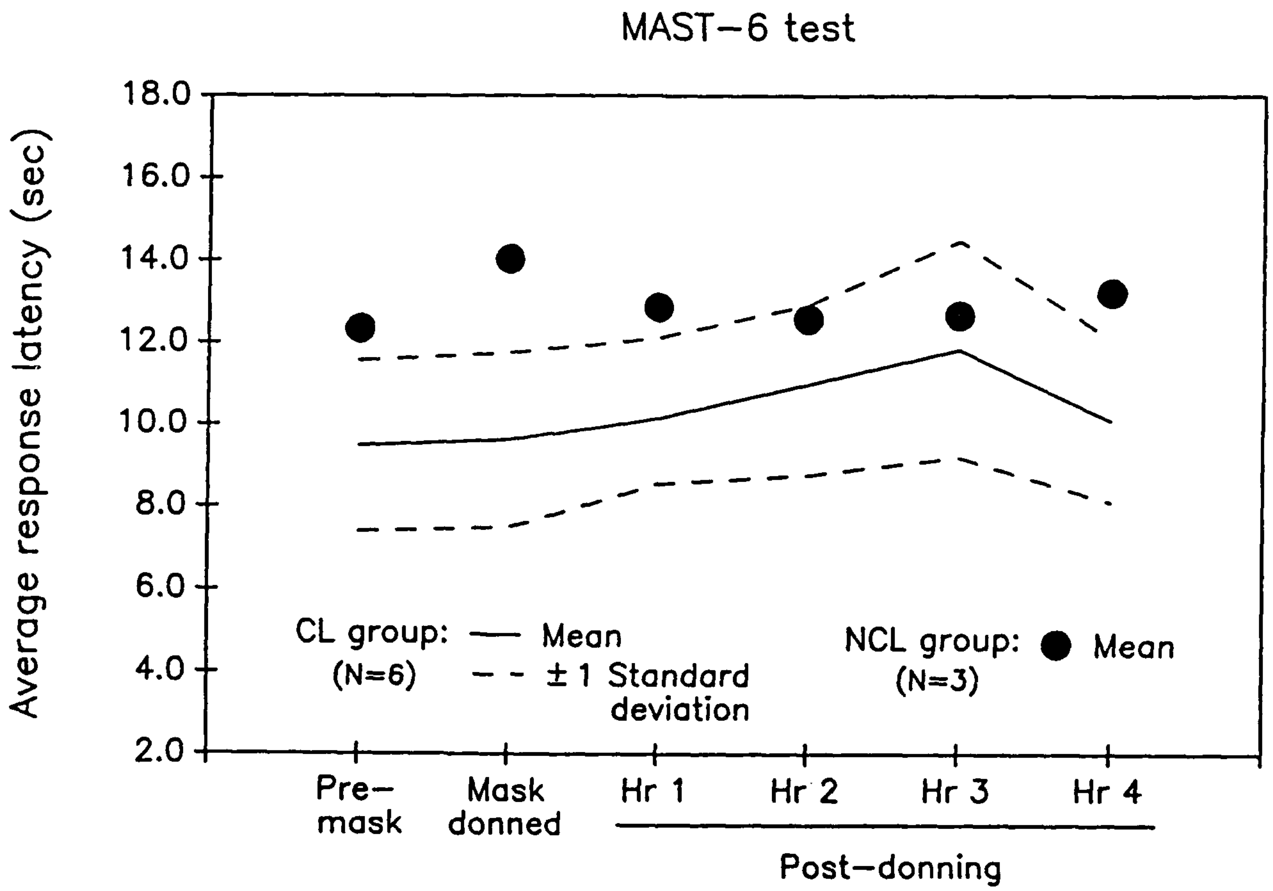

Figure 10. Mean reaction times on the MAST-6 test, a visual target detection task.

in measurement technique. Taken together, the results of these tests revealed no between or within group differences in physiological function.

Lens performance: Water content. Water content of the lenses measured in the premask phase averaged 52.5 percent, an hydrational loss after one night of lens wear of approximately 6 percent. Water content, following more than 4 hours of exposure to continuously blowing air, measured 54 percent, a nominal water loss of only about 4 percent. These differences were not statistically significant. Although concerns about excessive contact lens dehydration under the mask have a theoretical basis (Carter and Ewell, 1972), the water content data indicate acceptable fresh lens dehydration after more than 4 hours of continuous mask wear.

Questionnaire results. Inspection of the responses to question 1 revealed an absence of any effects associated selectively with either eye; therefore, in each group, the data from both eyes were pooled. (Responses from the unilateral CL wearer

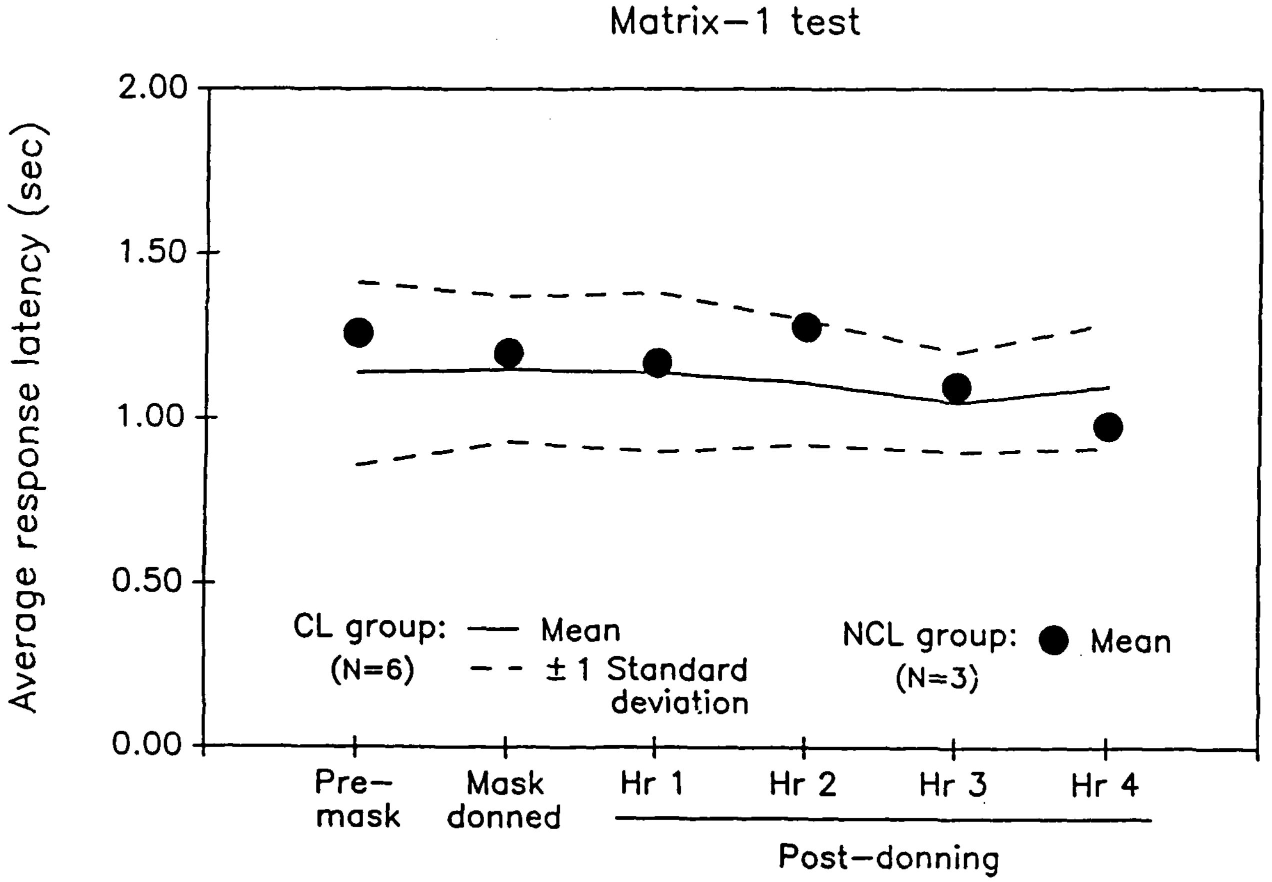

Figure 11. Mean reaction times on the Matrix-1 test, a test of visual short-term spatial memory.

was divided appropriately between the two groups yielding a total of 11 CL and 13 NCL eyes). For each category of comfort or visual quality, subjective "effects" were determined by tallying all "nonnormal" (i.e., non-0 or "not at all") responses and then comparing the resultant frequency to an arbitrarily-determined criterion frequency. Criterion frequencies for the CL and NCL groups were set at five and six, respectively (i.e., 45 and 46 percent of the total number of CL and NCL eyes). At any test phase, frequencies equalling or exceeding these criterion frequencies signalled the presence of a subjective "effect."

Based upon these procedures, subjective "effects" were noted among 5 of the 18 attributes used to assess ocular comfort and/or visual quality. After donning the mask, subjects in both groups reported the presence of eye irritation, eye dryness, focusing difficulty, and increased blinking. In addition, complaints of blurred vision were reported by members of the CL group. Figures 13-17 show these data in more detail.

As can be seen, the left panel in each of these figures represents the percentage of eyes in each group with responses

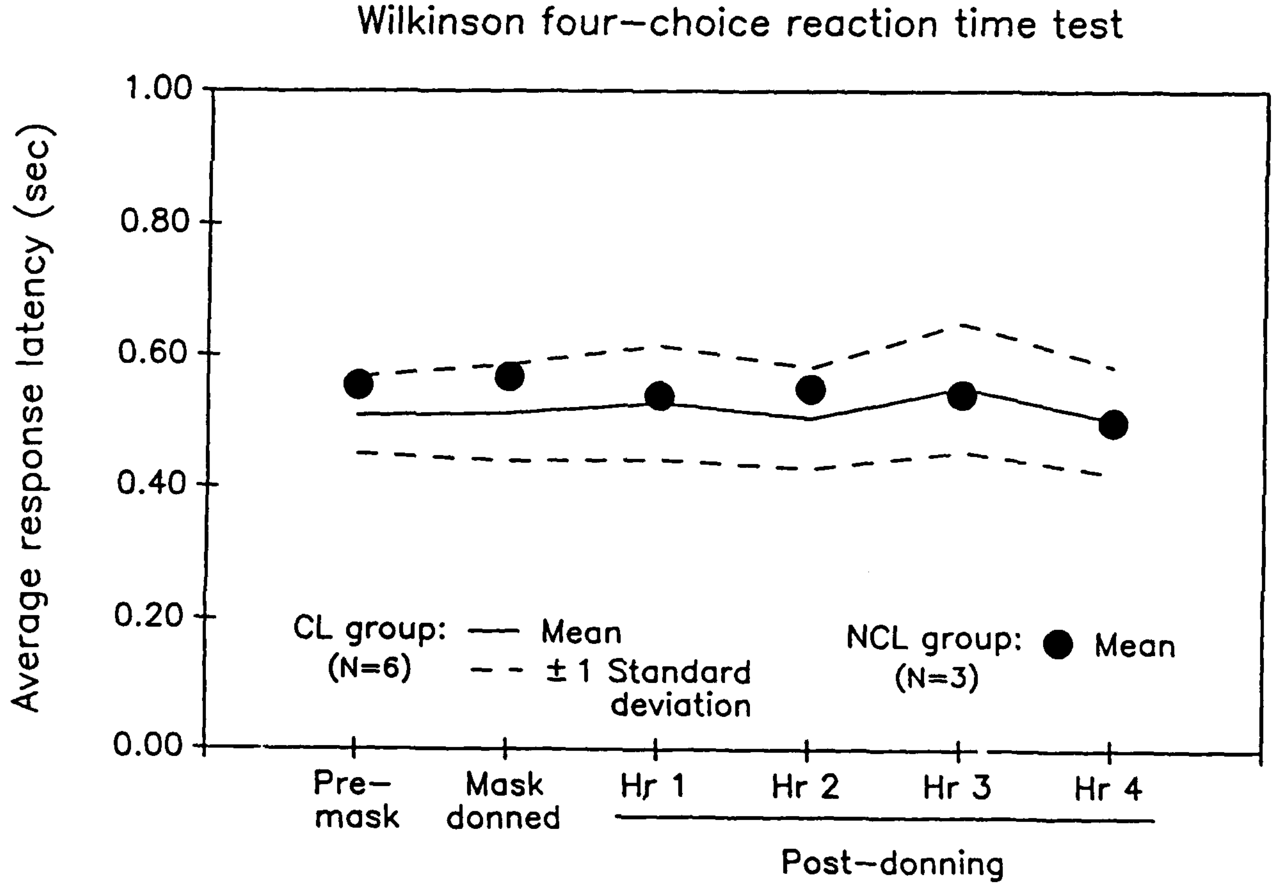

Figure 12. Mean reaction times on the Wilkinson test, a visual four-choice serial reaction time task.

Table 3.

Tear production, tear break-up time, and corneal thickness

Tear production (mm)

CL group	Premask		Postmask		NCL group	Premask		Postmask	
Subject	OD	OS	OD	OS	Subject	OD	OS	OD	OS
0001	22	15	35	26	0011	12	10	8	5
0002	14	23	17	27	0012	7	10	8	6
0003	16	18	13	20	0013	23	29	28	30
0004	7	12	10	8	0015	8	3	5	8
0005	22	22	15	11	0016	15	15	14	10
0007	9	--	5	--	0017	20	30	17	25
					0007	--	5	--	5
Mean*	16.2	18.0	18.0	18.4	Mean*	14.2	16.2	18.0	18.4

Tear break-up time (sec)

CL group	Premask		Postmask		NCL group	Premask		Postmask	
Subject	OD	OS	OD	OS	Subject	OD	OS	OD	OS
0001	13	12	12	10	0011	20	18	--	--
0002	8	10	15	16	0012	28	30	15	18
0003	20	23	16	17	0013	18	18	14	14
0004	9	10	5	8	0015	27	23	18	17
0005	8	9	10	10	0016	12	10	10	8
0007	6	--	12	--	0017	12	12	16	15
					0007	--	8	--	14
Mean*	11.6	12.8	11.6	12.2	Mean*	19.4	18.6	14.6	14.4

Corneal thickness (mm)

CL group	Premask		Postmask		NCL group	Premask		Postmask	
Subject	OD	OS	OD	OS	Subject	OD	OS	OD	OS
0001	.506	.554	.499	.542	0011	.558	.553	.526	.576
0002	.527	.587	.549	.596	0012	.521	.529	.506	.543
0003	.591	.605	.599	.592	0013	.541	.554	.546	.591
0004	.523	.518	.529	.527	0015	.620	.721	.631	.711
0005	.578	.622	.589	.584	0016	.448	.481	.438	.522
0007	.532	--	.537	--	0017	.593	.586	.552	.595
					0007	--	.542	--	.560
Mean*	.545	.577	.553	.568	Mean*	.547	.571	.533	.590

* Subject 0007 omitted from calculation of the means

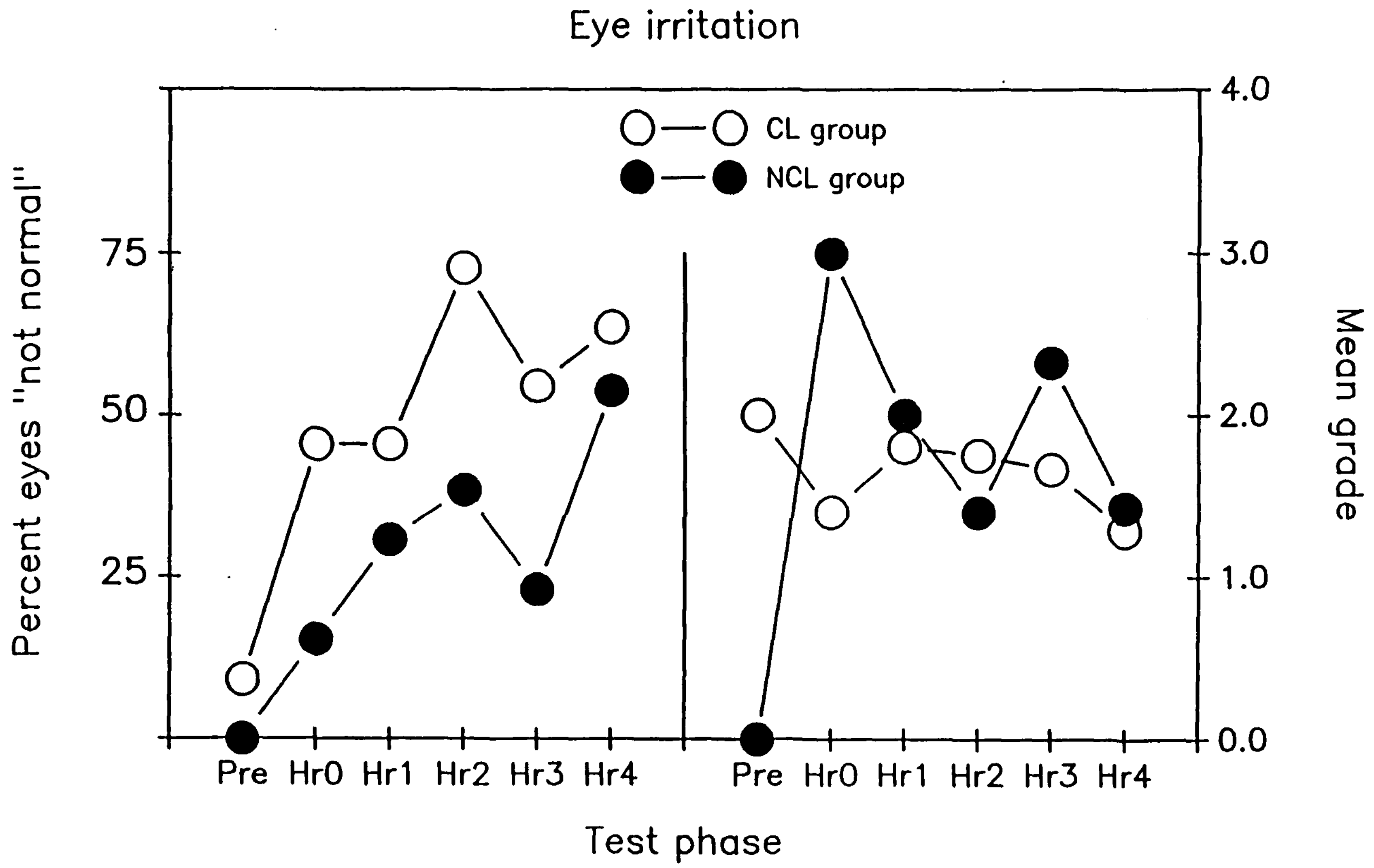

Figure 13. Eye irritation: Percentage and mean grade of "nonnormal" eyes (after Dennis et al., 1988).

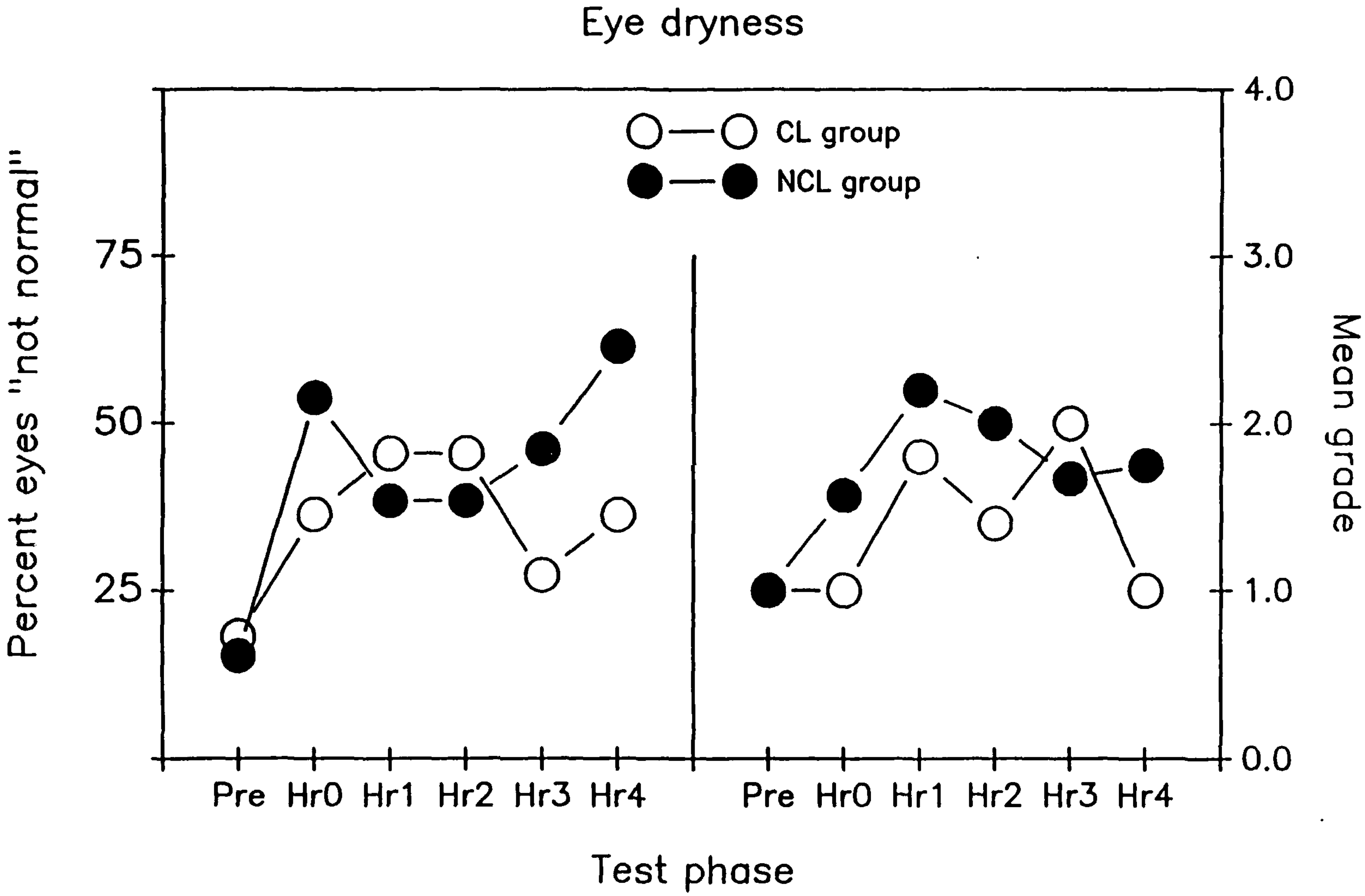

Figure 14. Eye dryness: Percentage and mean grade of "nonnormal" eyes (after Dennis et al., 1988).

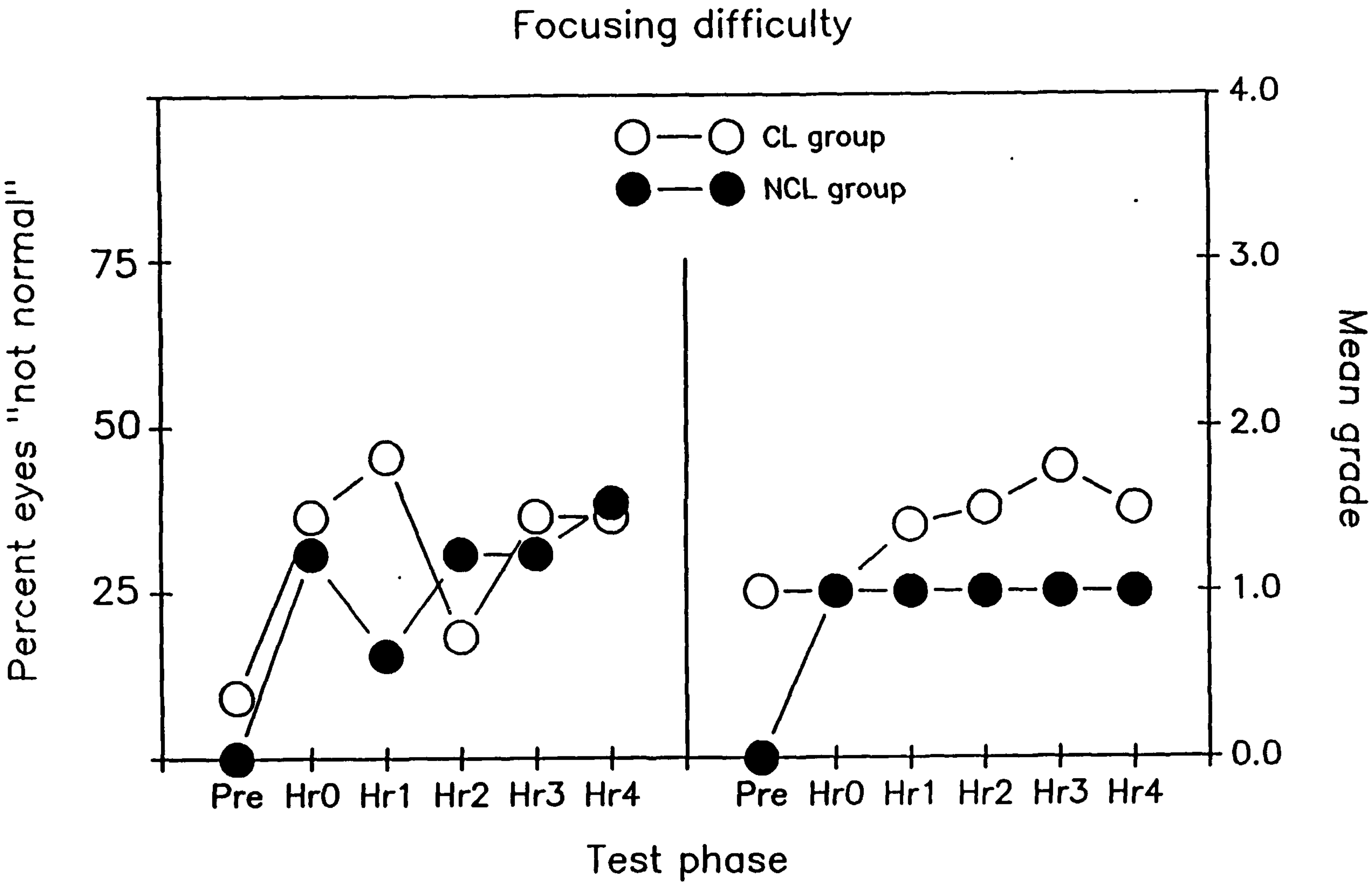

Figure 15. Focusing difficulty: Percentage and mean grade of "nonnormal" eyes (after Dennis et al., 1988).

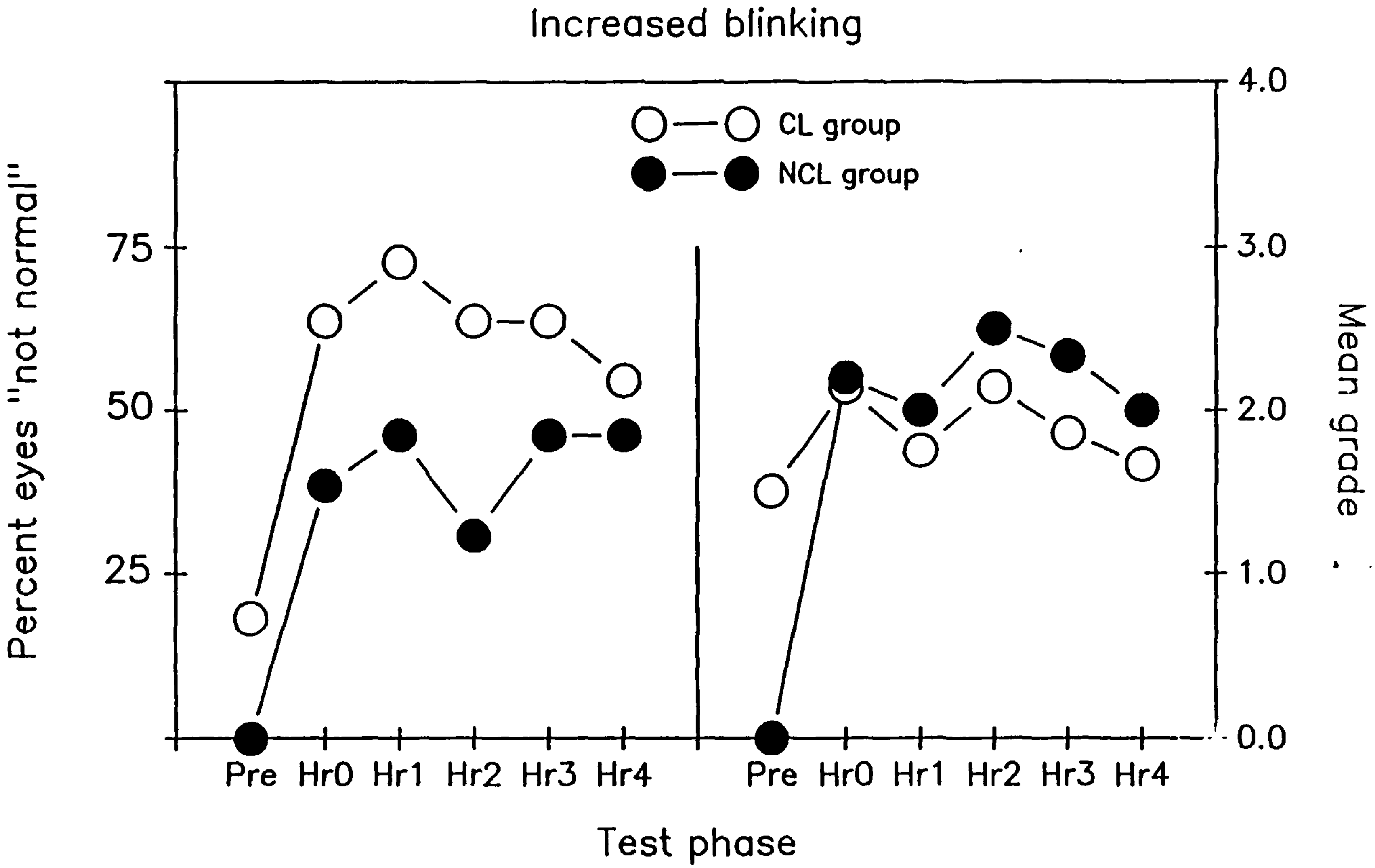

Figure 16. Increased blinking: Percentage and mean grade of "nonnormal" eyes (after Dennis et al., 1988).

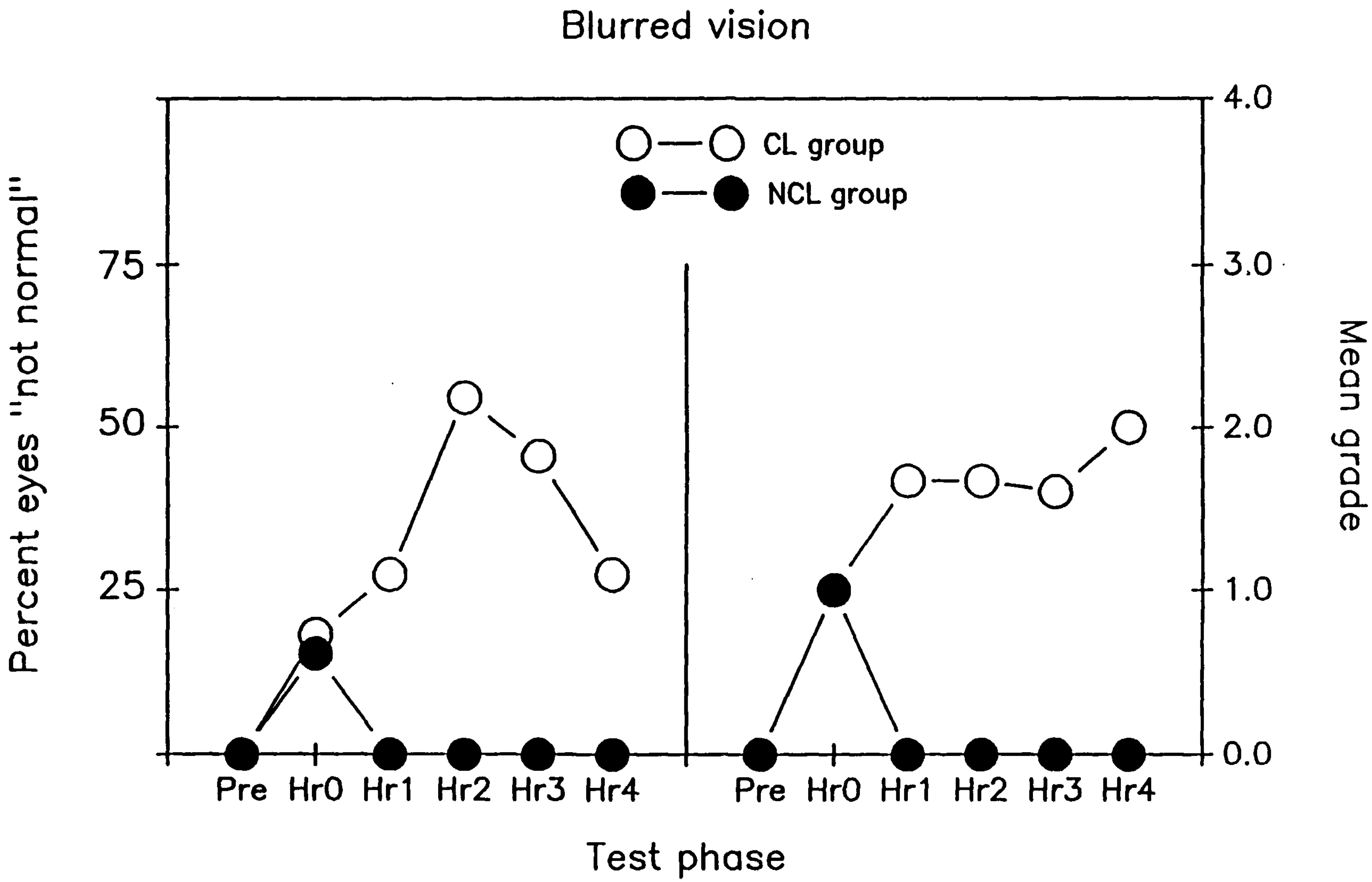

Figure 17. Blurred vision: Percentage and mean grade of "nonnormal" eyes (after Dennis et al., 1988).

other than "0" ("not at all") to the attributes listed above. The right panel indicates the average "complaint" grade of these "not normal" eyes. (The effects of including nonaffected eyes on the mean complaint grades of the first four subjective attributes are shown in Appendix F.) In general, attributes of subjective discomfort generally were rated from minimal to mild and never associated, at any phase, with all the eyes in either group. (Perhaps due to lingering effects of the physiological procedures or, in the case of lens wearers, inadequate adjustment time, these effects were sometimes present even before donning the mask.) Personal comments from symptomatic individuals indicated that these effects were due mainly to the mechanical irritation associated with the airflow (set at maximum) around the eyes.

Subjective estimates of visual ability (question 2) were identical in both subject groups over the first hour of testing (hours 0-1). Over the next 3 hours, however, subjective estimates of visual ability decreased among the contact lens relative to their emmetropic counterparts (Table 4). This was accompanied by a slight decrease in subjective comfort (question 3; Table 5) associated with wearing the lenses. (One CL subject also reported decentering of his lens, although upon inspection, the lens was found to be centered properly.) As measured by performance on both the visual function and cognitive tests, none of these subjective reductions in either ocular comfort or perceived visual quality resulted in any measurable effects on visual performance.

Discussion

The present study was conducted to assess both immediate and sustained effects of wearing the M-43 mask on several aspects of nonoperational visual performance among emmetropic aviators and ametropic aviators corrected with extended-wear soft contact lenses. In both groups, the distribution of air into the mask and the airflow around the eyes was adjusted to maximize ocular turbulence and encourage ocular and lens drying. For CL wearers, such "worse-case" effects could produce parametric changes in lens material (Andrasko and Schoessler, 1980) with subsequent effects on both lens fit and corneal physiology. Consequently, both user comfort and visual performance could be degraded. Clearly, any changes in aviator visual performance attributable to wearing the mask alone or in combination with contact lenses could impact flying performance and raise safety-of-flight issues.

Several workers have examined the effects of lens dehydration occurring within the low relative humidity environments characteristic of cockpits during high-altitude [low oxygen] flight (e.g., Eng, Rasco, and Marano, 1978; Hapnes, 1980; Forgie,

Table 4.

Questionnaire responses: Question 2

How would you rate your visual abilities while wearing the mask compared to your abilities without the mask?

Scale:
2.0 = much better with the mask
1.0 = slightly better with the mask
0.0 = the same with and without the mask
-1.0 = slightly worse with the mask
-2.0 = much worse with the mask

	CL group[1]					NCL group				
Hour	0	1	2	3	4	0	1	2	3	4
Ss[2]	4	3	5	5	5	4	3	2	2	3
Mean[3]	-0.67	-0.50	-0.83	-1.00	-0.83	-0.67	-0.50	-0.33	-0.33	-0.50
Mdn[4]	-1.00	-0.50	-1.00	-1.00	-1.00	-1.00	-0.50	0.00	0.00	-0.50

1 Includes the subject corrected monocularly; N=6 each group.
2 Number of subjects with non-0 responses.
3 Average rating, where a positive value indicates an improvement and a negative value a worsening of subjective visual ability through the mask.
4 Median rating.

1981; Flynn et al., 1985) or of heated commercial aircraft cabins [Daubs, 1972; Eng, 1979; Eng, Harada, and Jagerman, 1982]). Many of these workers have described a syndrome among contact lens wearers characterized primarily by minor corneal edema and lens discomfort. However, in all cases, changes in visual function typically have not been observed. Similar observations also have been noted in anecdotal reports from contact lens wearers exposed to drafts from open car windows, air conditioners, or other sources of moving air.

The results of the present study confirm the results from previous work discerning the existence of slight subjective discomfort and minor corneal insult resulting from sources of drying in and around the eyes. However, while slightly more prevalent in lens-corrected eyes, these effects characterized both CL and NCL wearing aviators and, more importantly, occurred independently of any measurable change(s) in visual performance.

Table 5.

Questionnaire responses: Question 3

How comfortable are your lenses at this point?

Scale:
2.0 = very comfortable
1.0 = comfortable
0.0 = neither comfortable nor uncomfortable
-1.0 = uncomfortable
-2.0 = very uncomfortable

Hour	Pre	0	1	2	3	4
Mean[1]	1.36	1.00	0.45	0.73	0.73	0.27
Mdn[2]	1.00	1.00	1.00	1.00	1.00	0.00

1 Mean rating from 11 lens corrected eyes
2 Median rating

In general, no significant impairment in visual function (visual acuity, contrast sensitivity, and color vision) or visually-based cognitive performance could be detected in both NCL or CL wearing subjects as a function of wearing the mask, either immediately after its donning or while wearing it over an extended period of time (4 hours). (It should be noted the mask, with or without correction, may restrict the wearer's field-of-view, and when worn with the helmet, hinder both head movement and compatibility with viewing instrumentation in the Apache cockpit [Davis and Smith, 1989].)

Recommendations

The results of this study indicate no adverse effects on either visual function or cognitive performance as a function of wearing the M-43 protective mask with or without soft contact lens correction. Although slight decreases in ocular comfort and temporary changes in corneal epithelial integrity and conjunctival injection were noted under the conditions of the present study, a more even distribution of air into the mask, and a concomitant reduction of airflow in and around the eyes, should greatly alleviate these problems. Because masks may be exposed to the debris typical of dusty helicopter environments, all aviators should, time permitting, turn on the blower and let the air tubes clear before donning the mask to preclude any dust related ocular problems.

Long-term health risks associated with contact lens wear are still speculative, medical supply and logistics issues are still unresolved, and potential long-range demands upon the Army's health care system are as yet unknown. Current work in this Laboratory is aimed at ocular health issues, user acceptance, and flight performance among contact lens wearing aviators. The results of this study indicate soft lens corrected pilots can wear their lenses successfully over a time period typical of a combat mission, and while donned in their M-43 masks, without the risk of impaired visual performance or breaching the visual medical fitness standards (at least where they exist for visual acuity) of AR 40-501.

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Appendix A

Subject age, refractive status, contact lens experience, and contact lens power

Sub-ject	Age (yrs)	Refractive error: OD Sph	OD Cyl	OD Axis	OS Sph	OS Cyl	OS Axis	Wearing time (mos)	Power OD	Power OS
Contact lens wearers										
0001	39	-1.75	-0.25	159	-1.50	-0.75	046	7	-1.50	-1.50
0002	28	-1.00	-0.25	095	-1.00	-0.75	097	9	-0.75	-1.25
0003	39	-1.25	-0.75	085	-2.00	-0.50	053	7	-1.25	-2.00
0004	27	-1.00	--	--	-1.25	-0.75	089	9	-0.50	-0.50
0005	27	-0.50	-0.50	089	-0.25	-0.75	089	2	-0.75	-0.75
0006	37	-0.25	-0.75	053	plano	-0.25	177	7	-0.50	n/a
Noncontact lens wearers										
0011	34	plano	-0.50	110	+0.25	-0.75	075	n/a	n/a	n/a
0012	34	plano	-0.25	076	+0.25	-0.75	102	"	"	"
0013	39	+0.25	-0.50	109	+0.50	-0.75	096	"	"	"
0015	25	plano	-0.25	102	+0.25	-0.50	104	"	"	"
0016	24	+0.25	-0.25	094	+0.50	-0.25	064	"	"	"
0017	21	+0.50	-0.50	091	+0.50	-0.50	080	"	"	"

Note: Subject 0007 has right eye correction only

Appendix B

Visual function tests

1. Bailey-Lovie high and low contrast acuity tests: These charts consist of 14 rows of 5 letters, each row decreasingly smaller. Letters on the high contrast chart appear black against the white background and have a nominal contrast of 90 percent, while letters on the low contrast chart appear light gray and have a nominal contrast of 8 percent. At the standard testing distance of 6 meters, the largest letters have a visual acuity requirement of 20/125 (logMAR 0.8) and the smallest letters have a visual acuity requirement of 20/6.3 (logMAR -0.5).

The letters were selected to be of almost equal legibility and consist of the ten 5 x 4 nonserifed letters (D E F H N P R U V Z) which were adopted in 1968 by the British Standards Institution (British Standard, 1968). Spacing between the letters is equal to 1 letter width; spacing between the rows equals to the height of the letter in the smaller row. Progression of letter sizes decreases geometrically by 0.1 log unit from the previous row. The chart is read from top to bottom.

2. Pelli-Robson test of contrast sensitivity: This chart consists of eight lines of six letters, each letter subtending a visual angle of 0.5 degrees at a viewing distance of 3 meters. This size letter is assumed to provide an estimate of contrast sensitivity equivalent to that obtained using sinusoidal gratings at a spatial frequency between 3 and 5 cycles per degree.

The letter font was developed by Sloan (1959) and the letter set consists of the 10 letters: C D H K O R S V, these being "about as nearly equal in legibility as can be obtained with simple capital letters." The chart contains is two-sided, each side containing a different, but nominally equivalent version of the test.

Each line of the chart contains two groups of three letters. The letters in each group are of equal contrast; however, the log contrast in successive groups are reduced by 0.15. The highest contrast group is in the left half of the topmost line and lowest contrast group is the right half of the bottom line. The chart is read from left to right and from top to bottom.

3. Lanthony color vision test (desaturated D-15 hue test): This test, adapted from the Farnsworth panel D-15, consists of 16 color chips selected from the Munsell book of color. The Munsell hues in the two tests are the same and were selected so that the intervals between the different hues are approximately the same.

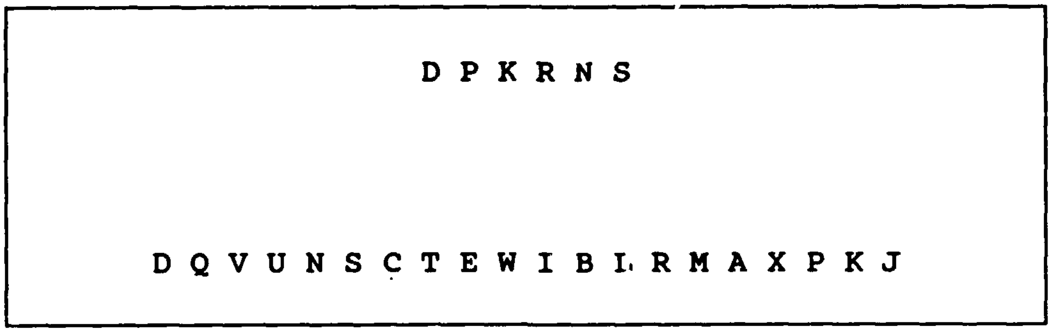
However, the purity (Munsell chroma) and the luminosity level (Munsell value) are different. In the standard test, the mean chroma is about 4.2 and the mean value is about 5.0; in the desaturated test, the chroma is 2.0 and the value is 8.0. As a result, the color chips of the desaturated 15-hue test appear paler and lighter than those of the standard test.

The test materials consist of a rack, color caps, and scoring sheets. The rack is made of two wooden hinged panels. The rack is made of two hinged wooden panels. The color chips are mounted on the top of plastic caps with scoring numbers on the undersurface. A reference cap is fixed permanently to the left end of the bottom panel of the rack. The remaining 15 caps are placed in random order on the upper panel of the rack. The subject's task is to arrange the color chips (caps) in order according to color. He is instructed to do this by first locating the color cap that most resembles the reference color cap and placing it next to it, then selecting the color cap that most resembles the last selected cap, etc. until all the caps are arranged in order. By closing the rack and turning it over, the scoring numbers become visible and the subject's arrangement can be transferred to the score sheet. If errors occurred, a plot of the scores is made and compared with examples of results obtained from both normal and color defective subjects, for global interpretation. Although not specifically recommended for this test, we have adapted the quantitative scoring scheme used for the Farnsworth FM-100 Test, in order to compare small differences in performance in normal observers on repeated retesting.

Appendix C

Sample cognitive test screens

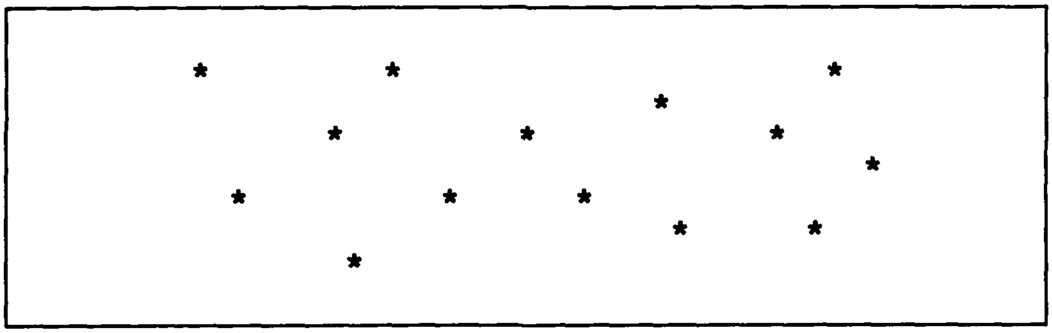
MAST-6 test



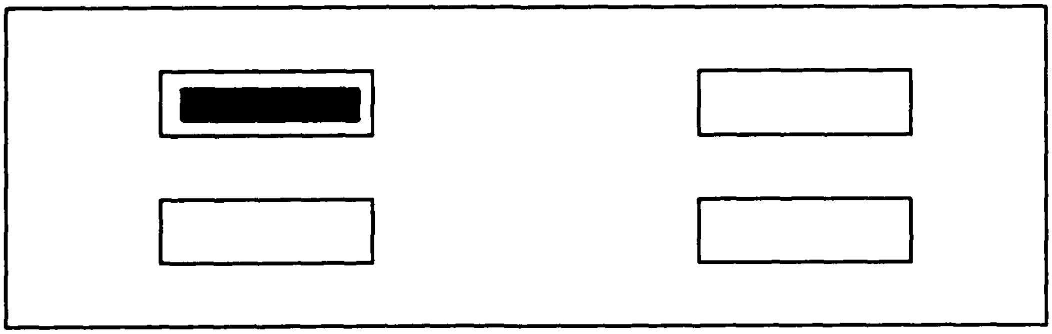
D P K R N S

D Q V U N S C T E W I B L R M A X P K J

Matrix-1 test



Wilkinson test



Appendix D

Subject questionnaire

INSTRUCTIONS

The purpose of this questionnaire is to assess your visual comfort while wearing the M-43 protective mask for AH-64 Apache pilots.

You will be administered this short questionnaire following each series of visual tests with and without the M-43 mask. Please answer the questions as accurately as possible. Your responses will be used in the evaluation of safety-of-flight issues.

Both you and your responses will remain anonymous. The data will be used for research purposes only. They will not become part of your medical or flight records nor will they be used to make any determination about you.

Thank you for your help.

1. To what extent are you experiencing:

						Which eye(s)?	
	Not at all	Very Minimal	Mild	Moderate	Severe	Right Eye	Left Eye
a. eyelid irritation	___	___	___	___	___	___	___
b. eye irritation	___	___	___	___	___	___	___
c. eye dryness	___	___	___	___	___	___	___
d. eye itching	___	___	___	___	___	___	___
e. eye pain	___	___	___	___	___	___	___
f. eye stickiness	___	___	___	___	___	___	___
g. blurred vision	___	___	___	___	___	___	___
h. fogged/hazy vision	___	___	___	___	___	___	___
i. distorted vision	___	___	___	___	___	___	___
j. increased light sensitivity	___	___	___	___	___	___	___
k. glare	___	___	___	___	___	___	___
l. double vision	___	___	___	___	___	___	___
m. focusing difficulty	___	___	___	___	___	___	___
n. fluctuating vision	___	___	___	___	___	___	___
o. increased tearing	___	___	___	___	___	___	___
p. increased blinking	___	___	___	___	___	___	___
q. sweat in the eye	___	___	___	___	___	___	___
r. halo(s) around lights	___	___	___	___	___	___	___
s. other (specify) ___	___	___	___	___	___	___	___
t. other (specify) ___	___	___	___	___	___	___	___

2. How would you rate your visual abilities while wearing the mask compared with your visual abilities without the mask?

a. ____ much better with the mask

b. ____ slightly better with the mask

c. ____ the same with and without the mask

d. ____ slightly worse with the mask

e. ____ much worse with the mask

Comments: ____

____

____

____

Any additional comments: ____

____

____

NOTE: THIS QUESTION IS FOR WEARERS OF CONTACT LENSES ONLY.

3. How comfortable are your contact lenses at this point?

Left Eye	Right Eye
a. ____ Very comfortable	a. ____ Very comfortable
b. ____ Comfortable	b. ____ Comfortable
c. ____ Neither comfortable nor uncomfortable	c. ____ Neither comfortable nor uncomfortable
d. ____ Uncomfortable	d. ____ Uncomfortable
e. ____ Very uncomfortable	e. ____ Very uncomfortable

Comments: ____

____

____

____

Appendix E

Test procedural flow diagram

Day 1

1) Informed consent
2) PAB testing
3) CL set #1 applied (at end of day 1)

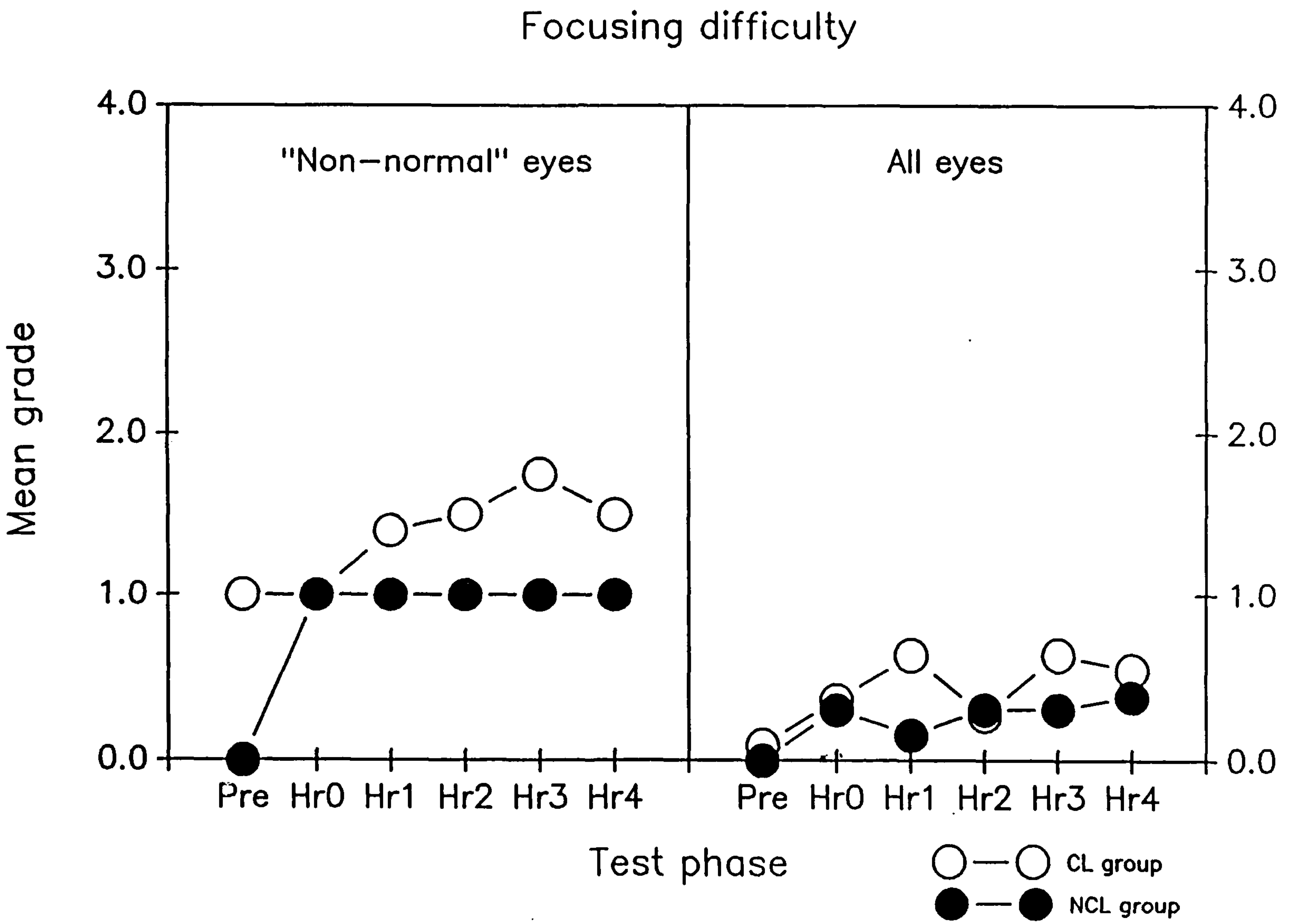
Day 2

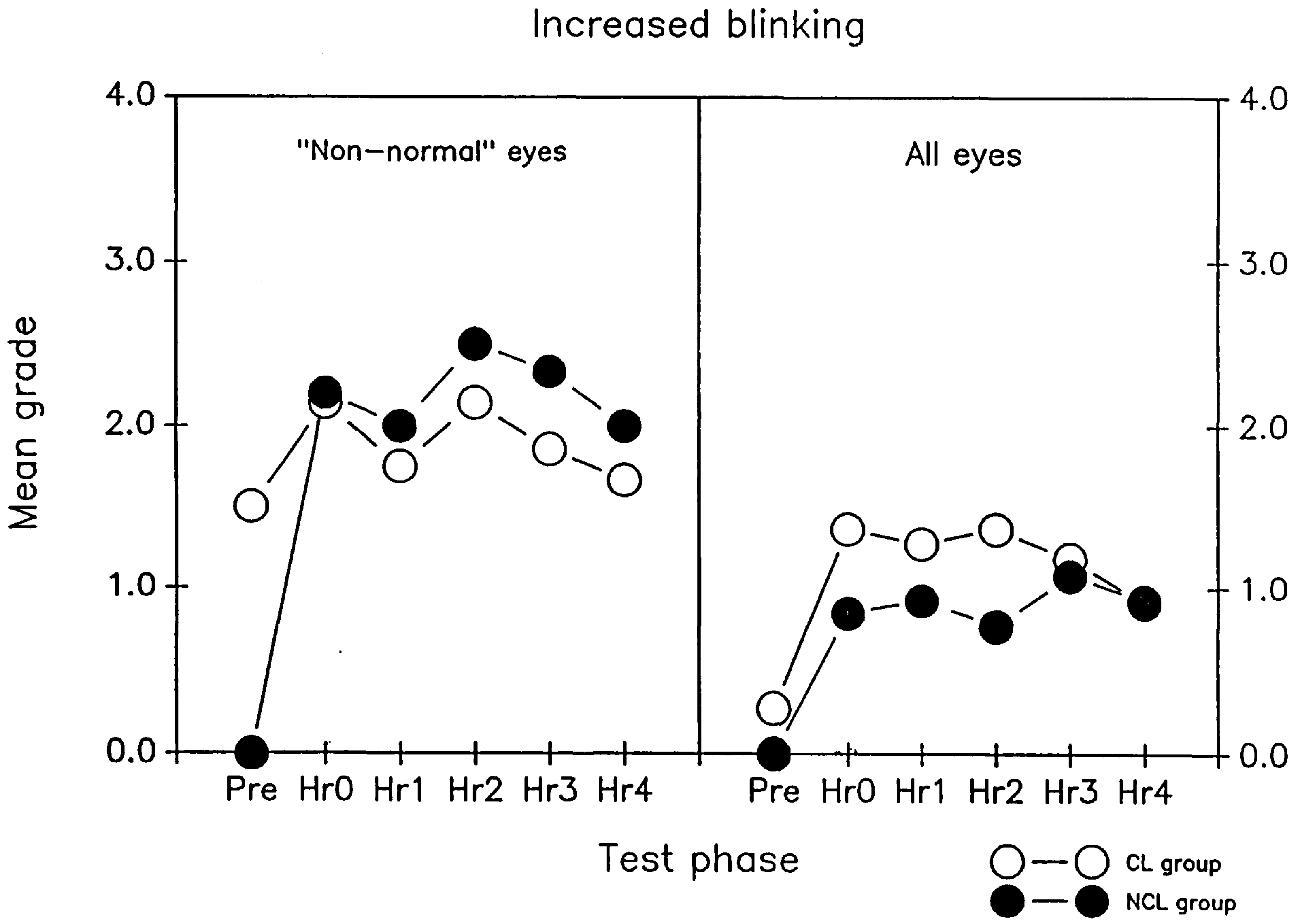
4) Visual/cognitive testing/questionnaire -- baseline measurements
5) CL set #1 removed/% water chronicled
6) Physiological/slit lamp assessment
7) CL set #2 applied
8) M-43 mask fit
9) Immediate visual/cognitive testing (through mask)
10) Mask worn 4 hours
11) Hourly visual/cognitive testing (through mask)
12) Mask removed after 4 hours wear
13) CL set #2 removed/% water chronicled
14) Physiological/slit lamp assessment
15) Exit debriefing

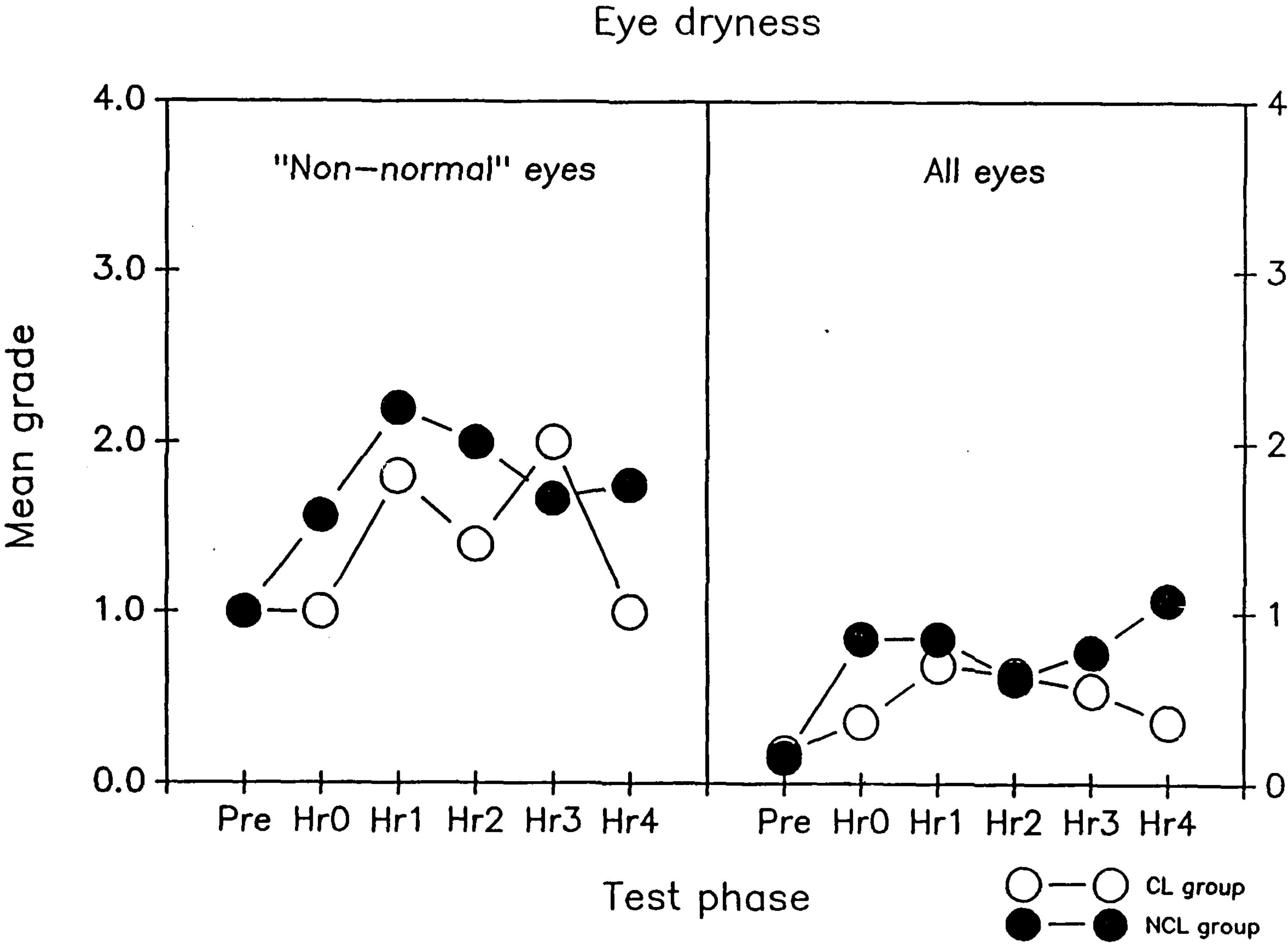
Contact lens-wearing subjects underwent all 15 steps in the above process; control subjects underwent steps 1, 2, 4, 6, 8, 9, 10, 11, 12, 14, and 15.

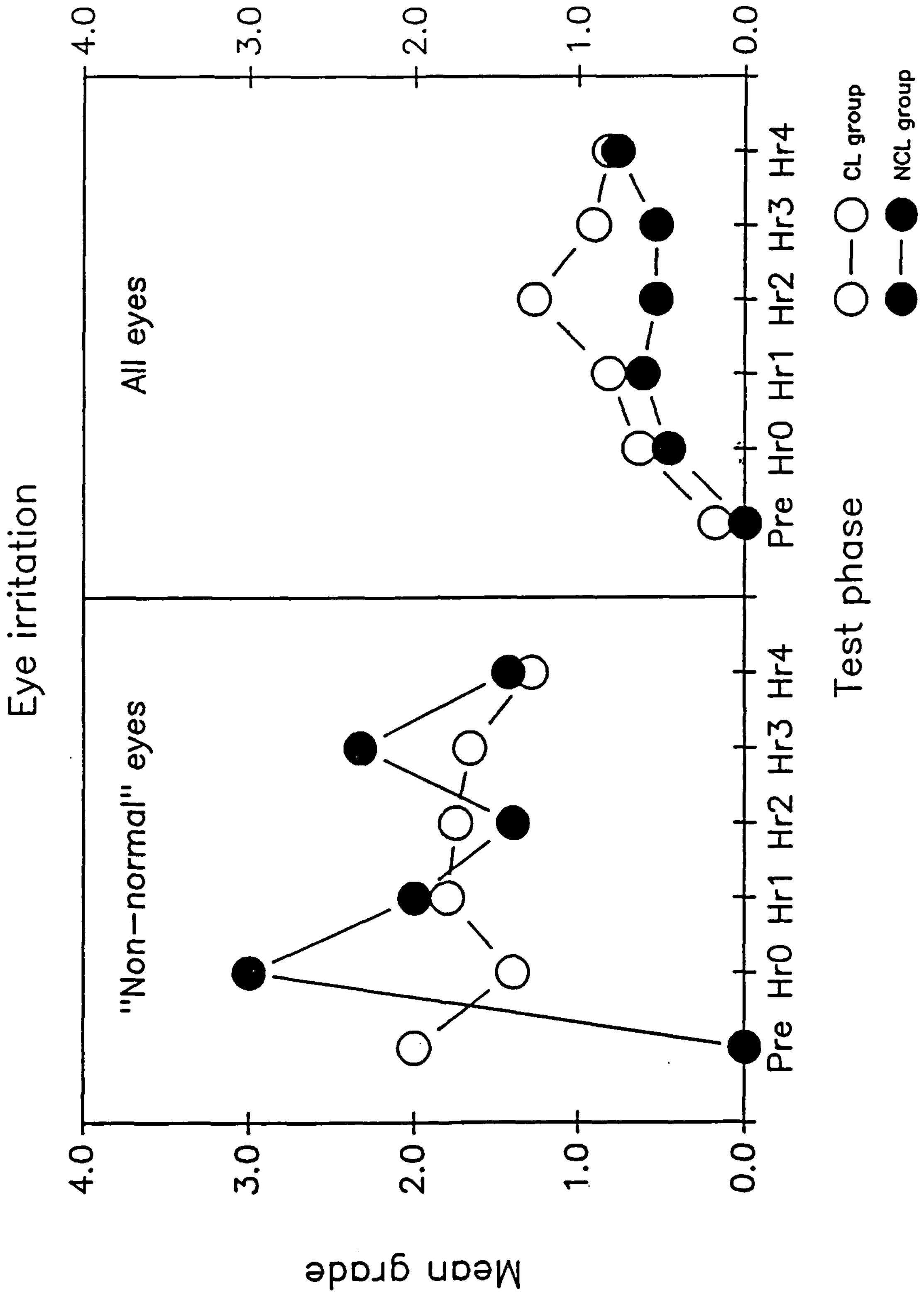
Appendix F

Subjective grades: "Nonnormal" eyes versus all eyes


Focusing difficulty
"Non–normal" eyes
All eyes
Mean grade
4.0
3.0
2.0
1.0
0.0
Pre
Hr0
Hr1
Hr2
Hr3
Hr4
Test phase
CL group
NCL group


Increased blinking
"Non−normal" eyes
All eyes
Mean grade
4.0
3.0
2.0
1.0
0.0
Pre
Hr0
Hr1
Hr2
Hr3
Hr4
Test phase
○—○ CL group
●—● NCL group


Eye dryness
"Non–normal" eyes
All eyes
Mean grade
4.0
3.0
2.0
1.0
0.0
Pre
Hr0
Hr1
Hr2
Hr3
Hr4
Test phase
CL group
NCL group


Eye irritation
"Non-normal" eyes
All eyes
Mean grade
0.0
1.0
2.0
3.0
4.0
Pre
Hr0
Hr1
Hr2
Hr3
Hr4
Test phase
CL group
NCL group

Appendix G

List of manufacturers

Arizona Instruments Corporation
Computrac Instrument Division
P.O. Box 1930
1100 East University Drive
Tempe, AZ 85281

Paravant Computer Systems
7800 Technology Drive
Melbourne, FL 32904

Vistakon, Incorporated
P. O. Box 10157
Jacksonville, FL 32247

Initial distribution

Commander U.S. Army Natick Research
and Development Center
ATTN: Documents Librarian
Natick, MA 01760

Naval Submarine Medical
Research Laboratory
Medical Library, Naval Sub Base
Box 900
Groton, CT 06340

Commander/Director
U.S. Army Combat Surveillance
and Target Acquisition Lab
ATTN: DELCS-D
Fort Monmouth, NJ 07703-5304

Commander
10th Medical Laboratory
ATTN: Audiologist
APO New York 09180

Naval Air Development Center
Technical Information Division
Technical Support Detachment
Warminster, PA 18974

Commanding Officer Naval Medical
Research and Development Command
National Naval Medical Center
Bethesda, MD 20014

Under Secretary of Defense for Research
and Engineering ATTN: Militar
Assistant
for Medical and Life Sciences
Washington, DC 20301

Commander
U.S. Army Research Institute
of Environmental Medicine
Natick, MA 01760

U.S. Army Avionics Research
and Development Activity
ATTN: SAVAA-P-TP
Fort Monmouth, NJ 07703-5401

U.S. Army Research and Development
Support Activity
Fort Monmouth, NJ 07703

Chief, Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal, NY 12189

Commander
Man-Machine Integration System
Code 602
Naval Air Development Center
Warminster, PA 18974

Commander
Naval Air Development Center
ATTN: Code 6021 (Mr. Brindle)
Warminster, PA 18974

Commanding Officer
Harry G. Armstrong Aerospace
Medical Research Laboratory
Wright-Patterson
Air Force Base, OH 45433

Director
Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

Commander U.S. Army Institute
of Dental Research
Walter Reed Army Medical Center
Washington, DC 20307-5300

Naval Air Systems Command
Technical Air Library 950D
Room 278, Jefferson Plaza II
Department of the Navy
Washington, DC 20361

Naval Research Laboratory Library
Shock and Vibration
Information Center, Code 5804
Washington, DC 20375

Director U.S. Army Human
Engineering Laboratory
ATTN: Technical Library
Aberdeen Proving Ground,
MD 21005-5001

Commander, U.S. Army Test
and Evaluation Command
ATTN: AMSTE-AD-H
Aberdeen Proving Ground,
MD 21005-5055

Director, U.S. Army Ballistic
Research Laboratory
ATTN: DRXBR-OD-ST Tech Reports
Aberdeen Proving Ground,
MD 21005-5066

Commander
U.S. Army Medical Research
Institute of Chemical Defense
ATTN: SGRD-W-AO
Aberdeen Proving Ground,
MD 21010-5425

Commander U.S. Army Medical Research
and Development Command
ATTN: SGRD-RMS (Ms. Madigan)
Fort Detrick, Frederick, MD 21701

Director
Walter Reed Army Institute of Research
Washington, DC 20307-5100

HQ DA (DASG-PSP-O)
5109 Leesburg Pike
Falls Church, VA 22041-3258

Naval Research Laboratory
Library, Code 1433
Washington, DC 20375

Harry Diamond Laboratories
ATTN: Technical Information Branch
2800 Powder Mill Road
Adelphi, MD 20783-1197

U.S. Army Materiel Systems
Analysis Agency
ATTN: Reports Processing
Aberdeen Proving Ground,
MD 21005-5017

U.S. Army Ordnance Center and School
Library Building 3071
Aberdeen Proving Ground,
MD 21005-5201

U.S. Army Environmental
Hygiene Agency
Building E2100
Aberdeen Proving Ground, MD 21010

Technical Library Chemical Research
and Development Center
Aberdeen Proving Ground,
MD 21010--5423

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Institute of Infectious Disease
Fort Detrick, Frederick, MD 21701

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Sciences Division
Office of Naval Research
600 North Quincy Street
Arlington, VA 22217

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U.S. Army Materiel Command
ATTN: AMCDE-XS
5001 Eisenhower Avenue
Alexandria, VA 22333

Commandant
U.S. Army Aviation
Logistics School
ATTN: ATSQ-TDN
Fort Eustis, VA 23604

U.S. Army Training
and Doctrine Command
ATTN: ATCD--ZX
Fort Monroe, VA 23651

Structures Laboratory Library
USARTL-AVSCOM
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665

Naval Aerospace Medical
Institute Library
Building 1953, Code 102
Pensacola, FL 32508

Command Surgeon
U.S. Central Command
MacDill Air Force Base, FL 33608

Air University Library
(AUL/LSE)
Maxwell Air Force Base, AL 36112

U.S. Air Force Institute
of Technology (AFIT/LDEE)
Building 640, Area B
Wright-Patterson Air Force Base,
OH 45433

Henry L. Taylor
Director, Institute of Aviation
University of Illinois-Willard Airport
Savoy, IL 61874

COL Craig L. Urbauer, Chief
Office of Army Surgeon General
National Guard Bureau
Washington, DC 50310-2500

Commander
U.S. Army Aviation Systems Command
ATTN: SGRD-UAX-AL (MAJ Lacy)
4300 Goodfellow Blvd., Building 105
St. Louis, MO 63120

U.S. Army Aviation Systems Command
Library and Information Center Branch
ATTN: AMSAV-DIL
4300 Goodfellow Boulevard
St. Louis, MO 63120

Federal Aviation Administration
Civil Aeromedical Institute
CAMI Library AAC 64Dl
P.O. Box 25082
Oklahoma City, OK 73125

Commander
U.S. Army Academy
of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234

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U.S. Army Institute of Surgical Research
ATTN: SGRD-USM (Jan Duke)
Fort Sam Houston, TX 78234-6200

AFAMRL/HEX
Wright-Patterson Air Force Base,
OH 45433

University of Michigan
NASA Center of Excellence in Man-Systems Research
ATTN: R. G. Snyder, Director
Ann Arbor, MI 48109

John A. Dellinger,
Southwest Research Institute
P. 0. Box 28510
San Antonio, TX 78284

Product Manager
Aviation Life Support Equipment
ATTN: AMCPM-ALSE
4300 Goodfellow Bouvclard
St. Louis, MO 63120-1798

U.S. Army Aviation
Systems Command
ATTN: AMSAV-ED
4300 Goodfellow Bouvelard
St. Louis, MO 63120

Commanding Officer
Naval Biodynamics Laboratory
P.O. Box 24907
New Orleans, LA 70189

U.S. Army Field Artillery School
ATTN: Library
Snow Hall, Room 14
Fort Sill, OK 73503

Commander
U.S. Army Health Services Command
ATTN: HSOP-SO
Fort Sam Houston, TX 78234-6000

Director of Professional Services
AFMSC/GSP
Brooks Air Force Base, TX 78235

U.S. Army Dugway Proving Ground
Technical Library, Building 5330
Dugway, UT 84022

U.S. Army Yuma Proving Ground
Technical Library
Yuma, AZ 85364

AFFTC Technical Library
6520 TESTG/ENXL
Edwards Air Force Base,
CA 93523--5000

Commander
Code 3431
Naval Weapons Center
China Lake, CA 93555

Aeromechanics Laboratory
U.S. Army Research and Technical Labs
Ames Research Center, M/S 215-1
Moffett Field, CA 94035

Sixth U.S. Army
ATTN: SMA
Presidio of San Francisco, CA 94129

Commander
U.S. Army Aeromedical Center
Fort Rucker, AL 36362

U.S. Air Force School
of Aerospace Medicine
Strughold Aeromedical Library
Documents Section, USAFSAM/TSK-4
Brooks Air Force Base, TX 78235

Dr. Diane Damos
Department of Human Factors
ISSM, USC
Los Angeles, CA 90089-0021

U.S. Army White Sands
Missile Range
Technical Library Division
White Sands Missile Range, NM 88002

U.S. Army Aviation Engineering
Flight Activity
ATTN: SAVTE-M (Tech Lib) Stop 217
Edwards Air Force Base, CA 93523-5000

Ms. Sandra G. Hart
Ames Research Center
MS 239-5
Moffett Field, CA 94035

Commander Letterman Army Institute
of Research
ATTN: Medical Research Library
Presidio of San Francisco, CA 94129

Mr. Frank J. Stagnaro, ME
Rush Franklin Publishing
300 Orchard City Drive
Campbell, CA 95008

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U.S. Army Medical Materiel
Development Activity
Fort Detrick, Frederick, MD 21701-5009

Commander, U.S. Army Aviation Center
Directorate of Combat Developments
Building 507
Fort Rucker, AL 36362

Chief
Army Research Institute
Field Unit
Fort Rucker, AL 36362

Commander
U.S. Army Safety Center
Fort Rucker, AL 36362

U.S. Army Aircraft Development
Test Activity
ATTN: STEBG-MP-QA
Cairns AAF
Fort Rucker, AL 36362

Commander U.S. Army Medical Research
and Development Command
ATTN: SGRD-PLC (COL Sedge)
Fort Detrick, Frederick, MD 21701

MAJ John Wilson
TRADOC Aviation LO
Embassy of the United States
APO New York 09777

Netherlands Army Liaison Office
Building 602
Fort Rucker, AL 36362

British Army Liaison Office
Building 602
Fort Rucker, AL 36362

Italian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Directorate of Training Development
Building 502
Fort Rucker, AL 36362

Chief
Human Engineering Laboratory
Field Unit
Fort Rucker, AL 36362

Commander U.S. Army Aviation Center
and Fort Rucker
ATTN: ATZQ-CG
Fort Rucker, AL 36362

President
U.S. Army Aviation Board
Cairns AAF
Fort Rucker, AL 36362

Dr. William E. McLean
Human Engineering Laboratory
ATTN: SLCHE-BR
Aberdeen Proving Ground,
MD 21005-5001

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Building 602
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German Army Liaison Office
Building 602
Fort Rucker, AL 36362

French Army Liaison Office
Building 602
Fort Rucker, AL 36362

Brazilian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Australian Army Liaison Office
Building 602
Fort Rucker, AL 36362

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6 Burning Tree Court
Bethesda, MD 20817

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Institute of Aviation Medicine
Farnborough Hants UK GU14 65Z

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Biosearch Company
3016 Revere Road
Drexel Hill, PA 29026