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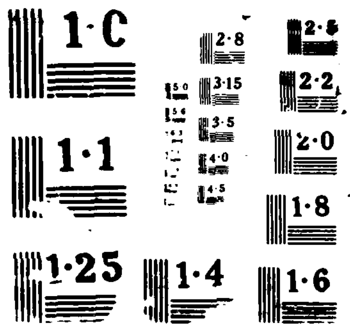
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A COMPARISON OF VISUAL EVOKED POTENTIAL AND BEHAVIORAL MEASURES OF FLASHBLINDNESS IN HUMANS

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September 1987

Final Report for Period September 1985 - October 1986

Prepared for
USAF SCHOOL OF AEROSPACE MEDICINE
Human Systems Division (AFSC)
Brooks Air Force Base, TX 78235-5301

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT: [illegible]

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S): [illegible]

6a. NAME OF PERFORMING ORGANIZATION: [illegible] International Technology Services Division

6b. OFFICE SYMBOL (If applicable)

6c. ADDRESS (City, State, and ZIP Code): [illegible] San Antonio, TX [illegible]

7a. NAME OF MONITORING ORGANIZATION: [illegible]

7b. ADDRESS (City, State, and ZIP Code): [illegible]

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

8c. ADDRESS (City, State, and ZIP Code)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: [illegible]

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
[illegible]	[illegible]		

11. TITLE (Include Security Classification): A Comparison of Visual Evoked [illegible]

12. PERSONAL AUTHOR(S): [illegible], Fred [illegible] and Allen, Ralph [illegible]

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM 85 [illegible] TO [illegible]

14. DATE OF REPORT (Year, Month, Day): [illegible], September

15. PAGE COUNT: [illegible]

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
[illegible]	[illegible]	
[illegible]	[illegible]	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): [illegible]

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

[illegible] response to [illegible]

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: [illegible]

22a. NAME OF RESPONSIBLE INDIVIDUAL: [illegible]

22b. TELEPHONE (Include Area Code) | 22c. OFFICE SYMBOL

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

TABLE OF CONTENTS

Figures

Tables

A COMPARISON OF VISUAL EVOKED POTENTIAL AND BEHAVIORAL MEASURES OF FLASHBLINDNESS IN HUMANS

INTRODUCTION

Flashblindness has been defined as "transient blindness which results when natural adaptation processes occur over an extreme range" (1). The nature of flashblindness has been widely investigated in humans using behavioral techniques (see ref. 2 for a review), and in monkeys using both behavioral as well as electrophysiological measures such as visual evoked potentials (VEPs) (3-6) and single-neuron recordings (7). Monkey subjects have been used exclusively whenever laser exposures near the damage threshold have been used to create the flashblindness effects. Since the rhesus monkey (Macaca mulatta) possesses a visual system which, in most respects, is highly comparable to that of the human (8-10), this species was chosen in developing animal models of laser-induced flashblindness.

In obtaining VEP correlates of laser flashblindness, an anesthetized, paralyzed rhesus monkey preparation has been used. The advantages of such a preparation include rapid data acquisition (i.e., no extensive behavioral training) and the relative ease of maintaining precise visual alignment of the test stimulus and laser flash. The principal disadvantage of the animal VEP model has been in interpreting changes in VEP amplitude following the flash with changes in the actual perception of the test stimulus. On the basis of numerous studies (11-15), it has been shown that changes in VEP amplitude correlate highly with changes in the contrast of a grating, although the precise relationship (i.e., linear, log, double linear) has not yet been resolved. It is, however, generally accepted that the grating contrast which first elicits a measurable VEP is similar to the behaviorally determined contrast threshold (15,16). Based on this assumption, the VEP has been used to predict the moment of initial visibility of test gratings following a wide range of laser flash exposures. In fact, the correlation between VEP estimates of visual recovery in rhesus monkeys and the predictions of the Czeh et al. (17) flashblindness model for humans is a highly significant one (r=.90) (see Fig. 1 and the Appendix).

Although the just mentioned correlation is impressive, it is not clear whether deviations from the predicted Czeh recovery times are due to flaws in the assumptions underlying the VEP itself, or to unrelated factors involving the different species, anesthesia regimens, use of laser sources, etc. Thus, the purpose of this study was to examine more precisely the relationship between VEP and behavioral measures of contrast perception during recovery from flashblindness, using VEP and behavioral measures recorded concomitantly from a group of human subjects exposed to intense but nondamaging flashes. A previous investigation (18) demonstrated a good correspondence in humans between loss of VEP amplitude and loss of behavioral visibility immediately following exposure to intense noncoherent flashes, although precise quantitative VEP recovery estimates were not derived in that study.

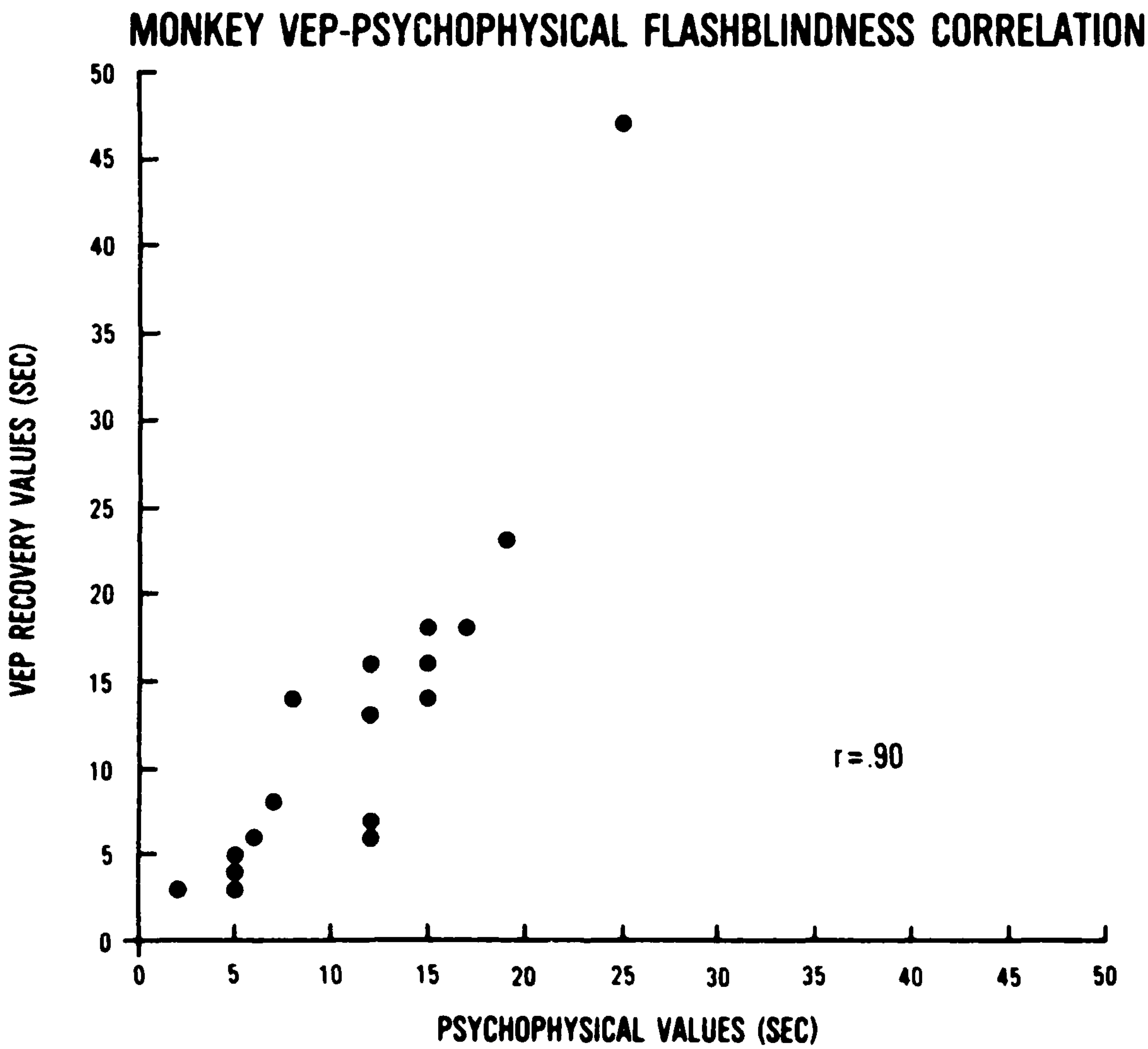


Figure 1. A comparison of flashblindness recovery times under various conditions as predicted from the Czeh et al. flashblindness model (17) and the monkey VEP data from several studies (2-4). See appendix for details.

METHOD

Subjects

Six adult humans, all of whom had served in previous VEP studies, served as volunteer subjects in the experiment. These subjects were either military and civilian personnel at the USAF School of Aerospace Medicine or employees of KRUG International. All subjects possessed natural or corrected binocular and monocular (right eye) visual acuities equal to or better than 20/25.

Procedure

Visual Presentation

A three-channel optical system, described in an earlier report (2), was used to present the adapting flashes and test stimuli used in this study. Two of the channels -- those used to present the adapting flash and a surround field -- used Maxwellian optics, whereas the test field was presented in natural view. The test stimuli used in this experiment were square-wave gratings which varied in their fundamental spatial frequency (1, 4, and 12 c/deg). The gratings were presented on a Mitsubishi M-6940 CRT at a mean luminance of 10 cd/m^2. The gratings were contained in a circular display whose diameter subtended 3.5 deg, at a viewing distance of 4 m. The gratings were counterphased using a 3-Hz square waveform (i.e., 6 phase reversals/s), and were presented at 50% contrast. A Photo Research Litemate III photometer was used for all photometric calibrations.

The adapting flash, which subtended 5 deg in diameter, was superimposed upon the test field, and was produced by a 1000-W xenon arc lamp (Oriel Corp. #6271). The output of the xenon source was controlled by a Uniblitz SD-10 shutter-timer so as to produce a 125-ms pulse. The energy of the flash (688 uJ, or 7.3 log td-s) was equal to 4% of the human maximum permissible exposure (MPE) to lasers in the 400-700 nm range (19). A Scientech 362 meter was used to monitor the power of the xenon output.

The annular surround field, presented in the second Maxwellian channel, was designed to, among other things, aid the subject in maintaining Maxwellian view throughout the entire flash trial. Its outer diameter subtended 12 deg, and its inner one slightly overlapped the outer boundary of the stimulus field. The luminance of the surround was psychophysically matched to that of the test field. A viewing support containing head and chin rests also assisted the subject in maintaining proper fixation in Maxwellian view. All viewing throughout the experiment was monocular, using the right eye.

Visual Evoked Potential Recording

The VEPs were generated in response to each phase-reversal of the grating, which occurred six times per second. The VEPs were recorded using a Grass E5-G gold-cup source electrode placed on the midline occipital scalp (O_z), and a reference electrode attached to the right earlobe. A ground lead was attached to the other ear. Electrode resistances were maintained below 10 Kohms using Grass EC-2 electrode cream. The VEPs were recorded in an electrically shielded room and amplified using Grass 7P511 solid-state amplifiers at a gain of 20,000, with low- and high-pass filter settings at 1 and 100 Hz. The resulting 6-Hz steady-state VEP waveform was then digitized at a rate of 256 Hz. Data analysis was performed using a PDP 11/34 computer.

The VEPs were recorded for a total of 20 trials in the 1 and 4 c/deg conditions, and for a total of 30 trials at 12 c/deg (because of the poorer signal-to-noise ratio in this condition). A trial consisted of (a) two 15-s baseline periods at the beginning and end in which a homogeneous field was presented, (b) a 30-s preflash stimulus epoch, (c) the presentation of the flash at 45 s, and (d) a 90-s postflash recovery interval. A brief tone signaled the beginning and end of the trial, and also randomly preceded the presentation of each flash by a few seconds. The subject was required to press a microswitch whenever the grating first became visible following the flash.

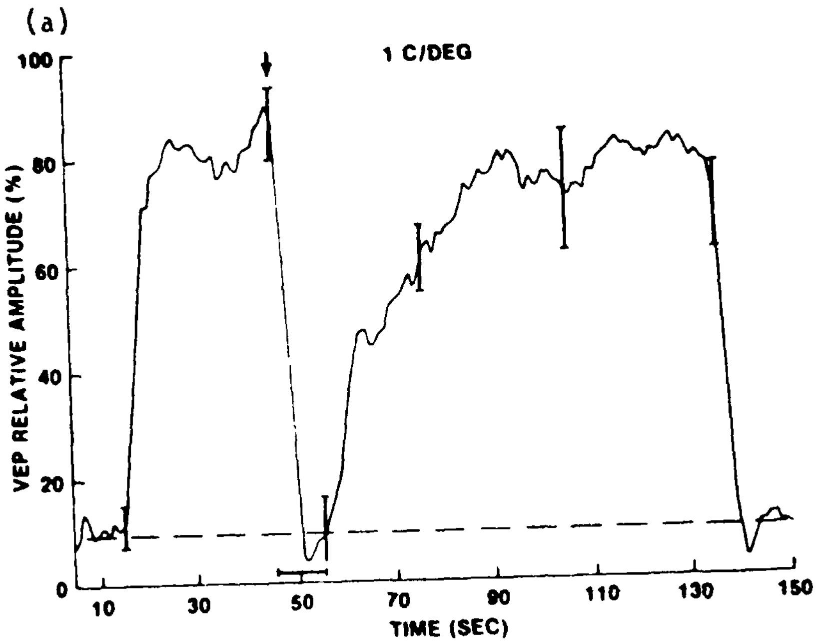
The exposure trials were run in individual replications consisting of 10 trials each. The three spatial frequency conditions were counterbalanced across the six subjects and were run in reverse order for each subject during succeeding replications. The entire experiment was run in four sessions lasting no more than 2.5 h each. The time between trials was approximately 5 min.

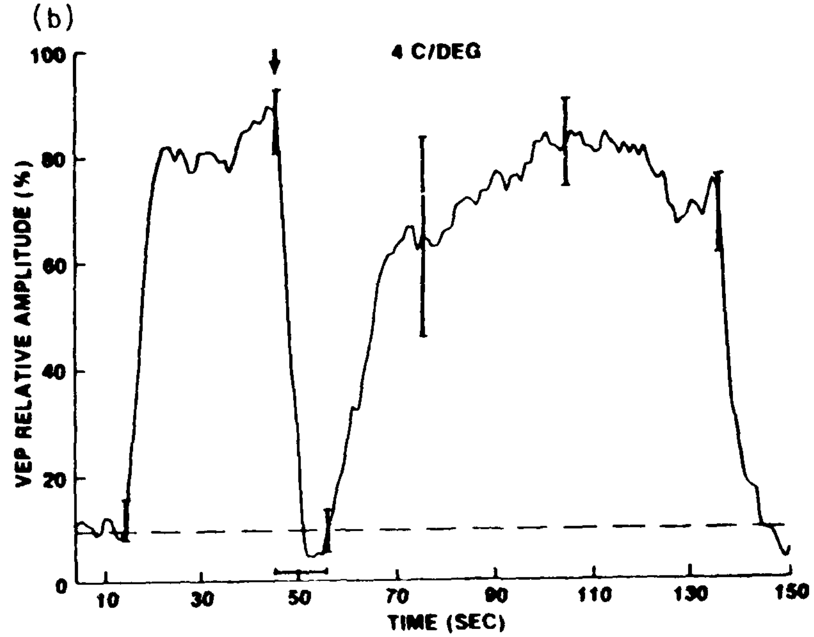
The VEPs were averaged over all trials and then subjected to a Fourier analysis. The VEP amplitudes were based on the Fourier power at the grating-reversal frequency (6 Hz). Each VEP amplitude measurement was made at successive 5-s intervals throughout the trial using a 1-s "sliding" offset.

RESULTS

The results for each of the three spatial frequencies are shown in Figure 2a-c. In this figure, VEP amplitudes for each subject were transformed into percentile values, with the lowest and highest VEP amplitude values throughout the trial set to 0 and 100%, respectively. The arrow indicates the moment at which the flash was presented; the bounded line just above the x-axis denotes the period during which the grating was invisible as reported by the subject; and the dotted line indicates the average VEP amplitude during the two baseline intervals. The error bars reveal the 95% confidence limits for each of the functions.

As shown in this figure, the initial appearance of the grating following the flash closely approximated the initial recovery of the VEP above its baseline level. The onset of grating visibility was estimated from the VEP according to the procedure described in the Appendix. A comparison of the behavioral and VEP estimates, averaged across all six subjects, is shown in Table 1. The two measures yielded comparable recovery estimates, and at no spatial frequency did either the VEP or the Czeh estimates fall outside the 95% confidence limits for the behavioral recovery times. Although both the behavioral and VEP measures indicated a longer recovery time for the 12-c/deg grating, an analysis of variance (Tables 2 and 3) showed that the difference among the three spatial frequency





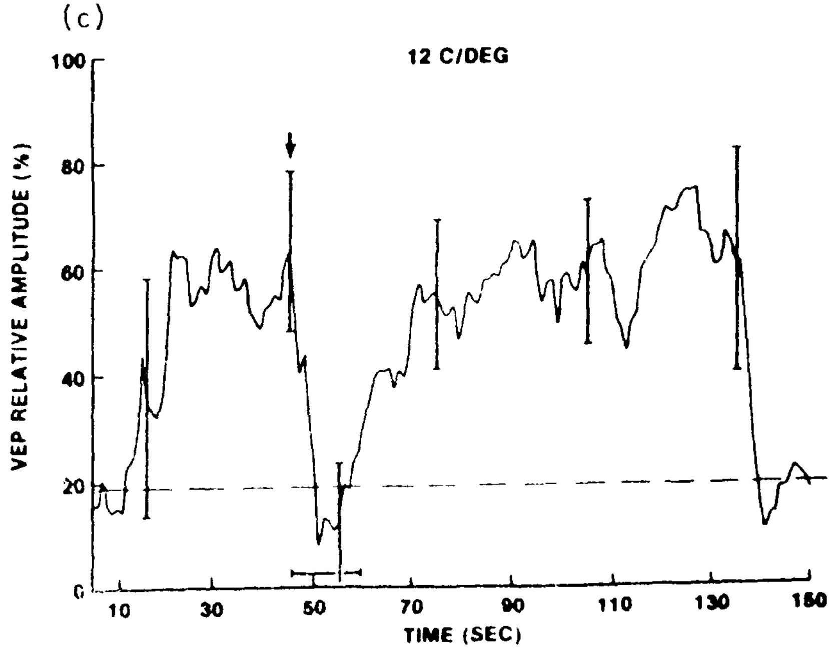


Figure 2. The effects of a 125-ms xenon flash (arrow) on VEP and behavioral measures of test grating visibility for three different frequencies: (a) 1 c/deg; (b) 4 c/deg; and (c) 12 c/deg. The VEP relative amplitude functions were derived from the VEP power at the 5-Hz phase-reversal frequency. The bounded lines just above the x-axis of each graph denote the postflash period during which the grating was behaviorally invisible to the subject. The dotted line indicates the average VEP amplitude during the baseline intervals, and the error bars denote the 95% confidence intervals. The functions represent the averaged data across all six subjects.

TABLE 1. A COMPARISON AMONG BEHAVIORAL, VEP, AND CZEH ET AL. ESTIMATES OF RECOVERY (ALL SUBJECTS)

	Mean Recovery (s)		
	1 c/deg	4 c/deg	12 c/deg
Behavioral	9.8 (±1.56)[a]	1[illegible].5 (±1.96)	14.8 (±2.36)
VEP	11.0	11.0	13.0
Czeh et al. model[b]	9.0	[illegible]	15.0

[a] 95% confidence intervals shown in parentheses.
[b] Values derived according to procedure described in Appendix.

Correlations:

Beh/VEP: r=+0.98
Beh/Czeh: r=+1.00
VEP/Czeh: r=+0.99

TABLE 2. ANALYSIS OF VARIANCE SUMMARY (BEHAVIORAL DATA)

Source	Deg of freedom (df)	Mean-square (MS)	F-ratio	p-value
Subjects	5	14.7	9.45	<.01
Spatial frequency	2	43.8	28.19	<.001
Error (subjects x spatial freq)	10	1.6		

TABLE 3. ANALYSIS OF VARIANCE SUMMARY (VEP DATA)

Source	Deg of freedom (df)	Mean-square (MS)	F-ratio	p-value
Subjects	5	140.9	2.50	>.10
Spatial frequency	2	155.2	2.75	>.10
Error (subjects x spatial freq)	10	56.4		

estimates was significant only for the behavioral measure ($F[2,10]=28.2$; $p<.001$). The mean estimate for the averaged VEP data at Γ and 4 c/deg ($\bar{x}=11.0$ s) was intermediate to those of monkey VEPs to 1, 2, and 4 c/deg high-contrast gratings following less intense flashes (6.5 log td-s); $\bar{x}=3.8$ s) and more intense flashes (8.5 log td-s; $\bar{x}=16.5$), as derived from the values listed in the Appendix.

A comparison of the VEP and behavioral estimates of recovery for each subject at each spatial frequency is shown in Table 4. Clearly, the two estimates for individual subjects do not correlate as well as for the entire group, as would be expected given the poorer VEP signal-to-noise (S/N) ratios for individual subjects. In fact, neither the correlations at each spatial frequency nor the pooled correlation across all frequencies proved significant. When matched against the Czeh et al. model's predictions, neither the behavioral nor the VEP recovery estimates for individual subjects correlate as well as do the average monkey VEP estimates ($r=.70$ [human behavioral]; $r=.44$ [human VEP]; $r=.90$ [monkey VEP]). On the other hand, both the average human VEP and behavioral estimates listed in Table 1 correlate nearly perfectly with the model ($r=.99$ and 1.00, respectively), although these were based on only a limited number of values.

TABLE 4. A COMPARISON BETWEEN BEHAVIORAL AND VEP ESTIMATES OF RECOVERY (INDIVIDUAL SUBJECTS)

	Mean Recovery (s)					
	1 c/deg		4 c/deg		12 c/deg	
Subject	Beh	VEP	Beh	VEP	Beh	VEP
JAZ	12.3	21	12.5	16	15.2	36
MEH	7.3	12	7.2	13	12.1	23
ETS	10.3	13	11.1	14	15.7	6
MFB	11.5	10	11.7	11	15.5	15
PVG	8.5	12	7.6	10	10.6	12
HMH	9.0	12	12.6	23	13.4	44*

*VEP estimates based on procedures described in Appendix, with exception noted. Recovery for HMH at 12 c/deg was not complete by 90 s using a 2-SD above baseline criterion, so the recovery estimate is based on a 1-SD criterion.

Correlations:

Beh/VEP (1 c/deg): r=+0.53
Beh/VEP (4 c/deg): r=+0.60
Beh/VEP (12 c/deg): r=+0.55
Beh/VEP (pooled): r=+0.57
Beh/Czeh (all data): r=+0.70
VEP/Czeh (all data): r=+0.44

DISCUSSION

The major purpose of this study was to determine the validity of the assumptions underlying the use of the VEP in predicting the duration of the visual loss following exposure to an intense laser flash. From the results, it appears that the assumptions underlying the VEP model [illegible] justified, given an adequate S/N in the VEP. The ability of the animal model to predict the extent of human flashblindness may be somewhat limited by species differences, anesthesia regimens, and other such factors; but the strong relationship shown in Figure 1 suggests that [illegible] serious threat to its overall validity.

The most striking evidence for the dependence of the [illegible] capability on a good S/N ratio is illustrated by the relatively [illegible] correlation between VEP and behavioral measures for individual subjects. The S/N ratios for individual subjects were far below those for the group (approximately 8:1 for 1 and 4 c/deg, and 4:1 for 12 c/deg), and were [illegible] poorer relative to those of typical bipolar recordings from as few as [illegible] trials in the monkey. Given the fact that the averaged VEP for all [illegible] human subjects was based on a total of 100 s of averaging time per sub[illegible]

(20 trials and a 5-s interval), it is unlikely that the S/N ratios in this study could be significantly improved upon, since the gain in S/N decreases exponentially with increasing averaging (20). Thus, it may be concluded that the VEP flashblindness model can validly be used in humans only if the VEP S/N exceeds a certain minimum value, which can typically be achieved only when data are averaged across individuals. On the other hand, the presence of far higher S/N ratios in monkeys (>20:1, in some cases) does not necessarily guarantee a greater predictive validity (relative to the Czeh model) than for the human VEP group data, thereby indicating that species differences, anesthesia regimens, slight refractive errors, etc. may additionally limit the accuracy of the animal VEP model's predictions.

The predictive validity of the VEP flashblindness model may also be limited in at least two other respects. First, VEP amplitude correlates better with contrast detection at threshold (15,16) than with perceived contrast at suprathreshold levels (see 11-15). Thus, the VEP may not be as useful at predicting perceived contrast at intermediate and later stages of recovery as it is in predicting initial visibility following the flash; although a VEP amplitude which lies between baseline and preflash levels may indicate that the test grating is visible, but at a reduced contrast. Second, the VEP may be limited in predicting behavioral changes following the flash when targets composed of color, as opposed to luminance contrast, are used. Although some evidence suggests that VEPs to red-green and other types of color contrast may be related to psychophysically determined color-contrast thresholds (21-23), the relationship may not be as strong during recovery from flashblindness (5).

CONCLUSIONS

The transient loss of visual function immediately following an intense xenon flash was of similar duration when measured both behaviorally and electrophysiologically in humans. The correlation between the two measures for the group data was much higher than for individual subjects, thereby suggesting that the predictive validity of the VEP requires that a certain minimum S/N ratio be attained. The predictive validity of monkey VEP recordings may be slightly less despite much higher S/N ratios, implying that the animal flashblindness model may be limited by factors unrelated to the VEP itself. In general, the results of this study and previous monkey flashblindness studies reinforce the belief that laser-induced flash-blindness is qualitatively similar to that induced by nonlaser sources, and may be successfully described, at least to a first approximation, by current flashblindness models.

ACKNOWLEDGMENT

We thank Michael Blankenstein, Tony Catalano, Paul Garcia, Mary Headley, Danny Shaw, Dr. Joseph Zuclich (of KRUG International, Technology Services Division); A1C Jo Ann Blando, SSgt Harvey Hodnett, Dr. Arthur Menendez, and CPT Elmar Schmeisser (of the Vulnerability Assessment Branch, Radiation Sciences Division, the USAF School of Aerospace Medicine) for their contributions to this study.

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APPENDIX

Monkey VEP/Human Psychophysical Flashblindness Recovery Time Comparisons

Laser Energy (td-s)	Target Relative Luminance (mL)	Target Acuity (min of arc)	Czeh et al. Times (s)	VEP Data (s)
5.8	3.8	15	2	3
6.5	3.8	30	5	3
6.5	3.8	15	5	4
6.5	3.8	15	5	4
6.5	3.8	15	5	4
6.5	2.5	15	5	5
6.5	3.8	7.5	5	4
6.5	3.8	5	6	6
6.5	1.3	15	7	8
6.5	3.8	2.5	9	14
7.8	3.8	15	12	6
7.8	3.8	15	12	7
7.8	3.8	15	12	13
7.8	3.8	15	12	16
8.5	3.8	30	15	18
8.5	3.8	15	15	14
8.5	3.8	15	15	16
8.5	3.8	7.5	17	18
8.5	3.8	5	19	23
8.5	3.8	2.5	25	47

NOTES:

1. The VEP recovery estimates are based on data obtained from references 2-4. The VEP recoveries are derived from an average of all VEP recordings in each experiment. However, the only conditions included are those in which (a) the flash was presented on the macula and overlapped the target, and (b) the color of the flash and target were the same. Recovery estimates are based on a 2 standard deviation above VEP baseline criterion for log transformed relative amplitudes, using software developed by A1C Jo Ann Blando. Two seconds were deleted from each VEP estimate to adjust for the 5-s averages used in these studies.

2. Psychophysical recovery estimates are based on predictions from the Czeh et al. model (16), using second-order equations. Luminance values in mL reflect difference between Lmax and Lmin, i.e., the difference between the "target" and "background" luminances (for gratings, this represents the difference between the light and dark regions). Acuity values are transformed from grating spatial frequency values, with bar-width expressed as minutes of visual arc. Recovery estimates for 8.5 log td-s, and 2.5 and 30 minutes of visual arc, are based on model extrapolations.

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