MONOCULAR DEPRIVATION AND CIRCADIAN INFLUENCES ON THE CFF

MONOCULAR DEPRIVATION
AND
CIRCADIAN INFLUENCES ON THE CFF

By

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SCOPE AND CONTENTS:

The Zubek effect (the CFF of the non-occluded eye in monocularly-deprived subjects shows an initial decrease followed by an increase) was investigated. The initial depression effect was confirmed, but, though greater in the deprived subjects, it was present in the control groups as well. This effect was found to be primarily due to circadian fluctuations in the CFF, the CFF increasing from 9:00AM to 12:00Noon and then declining. No evidence was found to support the earlier claim of an enhancement effect. The results are discussed in terms of hormonal influences on sensory functioning.

ACKNOWLEDGEMENTS

I would like to thank Dr. W.H. Heron for his encouragement and guidance throughout this research. The helpful suggestions of Drs. G.K. Smith and P.L. Newbigging were also appreciated.

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While the initial sensory deprivation research involved the restriction of several senses (Bexton, Heron, & Scott, 1954), more recent research has used single modality deprivation in order to investigate the interactions occurring between sensory systems. Intersensory effects have been reported following binocular visual deprivation (Zubek, 1969). These effects include a decrease in auditory, gustatory, olfactory, and tactual thresholds. More recently, Dusansky (1968) and Zubek and his associates at the University of Manitoba have investigated the interactions occurring within the visual system through studying the effects of monocular deprivation on visual perception. Both the occluded eye (the eye deprived of light and pattern vision) and the non-occluded eye (the eye receiving normal input) have been tested in these studies.

Dusansky (1968) found a significant increase in minimum separable visual acuity and the perception of curvature in the occluded and non-occluded eyes during a 48 hour deprivation period. Testing was conducted at 0, 6, 12, 24, and 48 hours after the start of deprivation. The increased sensitivity was present at all test times, the magnitude of the increase being unaffected by the duration of deprivation. There was also a definite trend towards decreased thresholds for brightness sensitivity, colour saturation, numerical recoghition, and geometric recogni-

tion in both eyes.

In an exhaustive series of studies conducted at the University of Manitoba, Bross and Zubek (1972) investigated the effect of monocular deprivation on the critical flicker frequency (CFF) of the occluded and non-occluded eyes. The initial study involved the occlusion of the dominant eye and the CFF of both eyes measured before and after one week of deprivation, the non-occluded eye being tested first. No significant changes in the CFF were found in either eye of the control subjects (who had no restrictions placed on their activities) nor in the occluded eye of the experimental subjects (who were confined to the laboratory). There was a significant increase in the CFF of the non-occluded eye, indicating enhanced temporal acuity. All experimental subjects showed this effect, the mean increase being 2.47 Hz with a range of 0.87 to 5.62 Hz. When the experiment was repeated and only the occluded eye tested, no significant changes were found.

The same procedure was again used to determine if a significant improvement in the CFF of the non-occluded eye would occur when the non-dominant eye was deprived. A significant improvement did occur although the magnitude of the change was slightly less than that found previously (1.84 Hz). Nine of the ten subjects showed this effect, the increases in the CFF ranging from 0.87 to 4.50 Hz. No changes were found in either eye of the control subjects or

in the occluded eye of the experimental subjects.

The changes in the CFF over time was next studied, the subjects being tested at intervals of 0, 1/3, 1, 2, 3, 5, and 7 days during deprivation. A progressive increase in the CFF of the non-occluded eye was observed, the increase being statistically significant at all but the 1/3 day test. At the end of the deprivation period, the mean increase was 2.34 Hz with a range of 0.62 to 4.14 Hz.

To determine the effect of confinement, Bross and Zubek confined subjects to the laboratory for 24 hours and measured the monocular CFF before and after the confinement period. No changes in the CFF were found, indicating that confinement alone does not influence the CFF.

Bross and Zubek's results are puzzling since Allen (1923) and Hollenberg (1924) observed a decrease in the CFF of the non-occluded eye following three hours of monocular deprivation. Zubek and Bross (1972) tested the hypothesis that there is an initial depression of the CFF followed by an enhancement by testing the non-occluded (non-dominant) eye at intervals of 0, 3, 6, 9, 15, and 24 hours during deprivation. An initial depression of the CFF was observed at the 3 and 6 hour tests followed by a trend towards increased sensitivity. The increase was statistically significant at the 24 hour test. Two different response patterns were observed in the experimental condition: one-third of the subjects showed a prolonged depression of the

CFF, the rest only a brief depression. Zubek and Bross (1972) felt that the first group of subjects were more apprehensive during deprivation than the second group although no measures of anxiety were made. No changes in the corresponding eye of the confined control subjects were observed. The graphs of the experimental and control conditions are shown in Figure 1. Figure 1 also shows the results of a second study in which the occluded eye was tested at similar intervals. Again, no statistically significant changes were observed.

It appears that monocular deprivation can have aftereffects. Bross and Zubek retested three subjects on post-deprivation days 3 and 7 and found that the CFF of the non-occluded eye was still elevated one week after deprivation. In a further study (Zubek & Bross, 1973a), they tested at intervals of 0, 1, 3, 5, 7, 9, 11, and 14 days during deprivation and on post-deprivation days 1, 3, 5, 7, and 14. Figure 2 shows the increase in the CFF during deprivation and the gradual return to the baseline level. In some subjects the baseline level had not been reached by post-deprivation day 14. A follow-up study using the same procedure indicated that no significant changes occur in the CFF of the occluded eye.

The final study in this series (Zubek & Bross, 1973b) investigated whether the depression-enhancement effect found in an earlier study (Zubek & Bross, 1972) could

Figure 1. Change in the CFF in occluded and non-occluded eyes. (From Zubek & Bross, 1972).

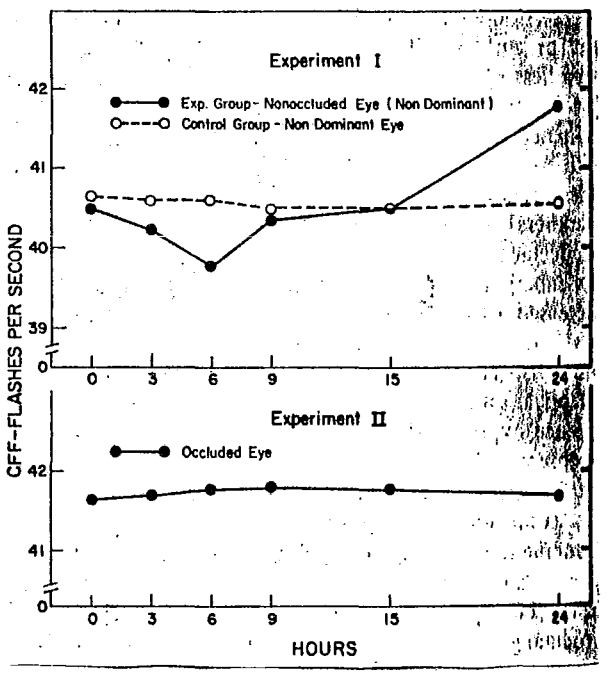
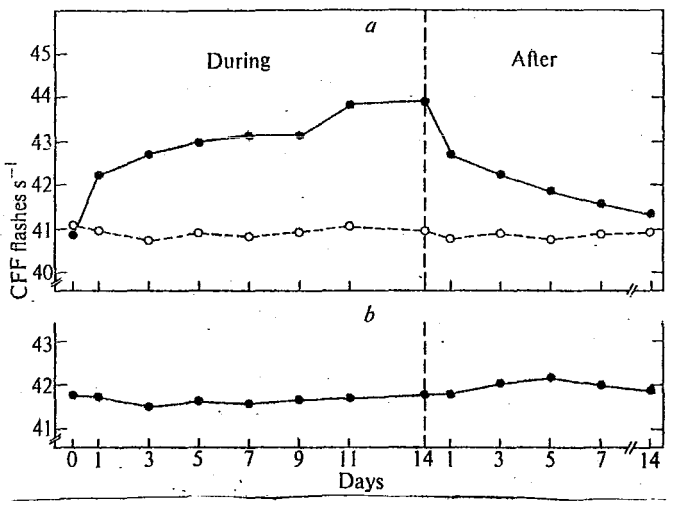

Experiment I
Exp. Group - Nonoccluded Eye (Non Dominant)
Control Group - Non Dominant Eye
CFF-FLASHES PER SECOND
42
41
40
39
0
0
3
6
9
15
24
Experiment II
Occluded Eye
42
41
0
0
3
6
9
15
24
HOURS

Figure 2. (a) Change in the CFF of the non-occluded eye of deprived subjects (filled circles) and the corresponding eye of control subjects (open circles) during and after 14 days of deprivation.

(b) Change in the CFF of the occluded eye of deprived subjects during and after 14 days of deprivation.

(From Zubek & Bross, 1973a).


a
During
After
45
44
43
42
41
40
CFF flashes s⁻¹
b
43
42
41
0 1 3 5 7 9 11 14 1 3 5 7 14
Days

be produced by a lack of pattern vision. A white translucent patch was placed on the dominant eye with the CFF of the non-occluded eye tested at intervals of 0, 3, 6, 9, 15, 24, 48, and 72 hours. No changes occurred in the CFF. When the occluded eye was tested in a subsequent study, the results were again negative.

There are several problems with the research conducted by Zubek and his associates. Most of the studies fail to adequately familiarize the subjects with the testing procedure before the start of the experiment. There is some evidence to suggest that the reliability of the CFF is low on the first few sessions with more reliable data obtained thereafter (Knox, 1945; Misiak, 1948; Landis, 1954). This initial unreliability of the CFF has been attributed (Landis, 1954) to the subject's gradual adoption of a suitable criterion. Given these results, it is possible that the lack of pretest sessions in the Manitoba studies is influencing the results obtained. A possible consequence of the lack of pretest sessions may be the large amount of between-subject variability present in the data. Bross and Zubek (1972), for example, found that the increase in the CFF ranged between 0.87 and 5.62 Hz. It is difficult to determine the generality of the phenomenon when the differences in individual performance are so great.

A final problem with the research is the failure to control for the effects of wearing an eye patch during the

testing sessions. A more appropriate control condition would involve the wearing of an eye patch during testing.

While some criticism can be made of the methodology, this series of experiments has confirmed time and again the observation that monocular deprivation causes an initial depression and later enhancement of the CFF of the non-occluded eye, the occluded eye being unaffected.

The question remains, however, as to the mechanism or mechanisms responsible for this unusual effect. Zubek (1972) attributes the depression-enhancement phenomenon to functional denervation supersensitivity within the visual system as a result of the disuse of neural pathways. The initial depression in the CFF is felt to reflect a stress reaction resulting from the subject's attempt to adjust to monocular vision (Zubek, 1972). The two enhancement periods (up to day 7 and between day 9 and day 11) may be due to the sequential disuse of two neural centers in the visual system (Zubek, 1972). This explanation does not, however, explain the failure to find any changes in the occluded eye. If functional denervation supersensitivity does underly the phenomenon then one might expect that the CFF of the occluded eye would be enhanced to an even greater degree during deprivation.

The nature of the phenomenon and the fact that the occluded eye is not affected by deprivation suggests that the interaction involves the facilitation of the neural

mechanisms associated with the non-occluded eye by those associated with the occluded eye. As this seemed a somewhat unusual pattern and as it is not improbable that it might be related to the problem of amblyopia, it was decided to investigate the matter further. First, however, confirmation of the phenomenon was in order.

MONOCULAR DEPRIVATION STUDIES

EXPERIMENT I: REPLICATION

Fifteen male and female paid subjects (Ss) who were naive about the experiment were selected from the student population at McMaster University for this experiment. Five Ss were randomly assigned to each of three groups: a monocularly deprived (MD), a patched control (PC), and a control (C) group.

Apparatus

A flicker-generating apparatus consisting of an optical system with an episcotister disk rotated at the nodal point was used.

The light source (Sylvania type CZR) and a converging lens were encased in a black hood with a transparent plastic window situated directly in front of the lens. The intensity of the light source was controlled by a rheostat (Powerstat type 117T). A square piece of tin was placed at the focal point of the converging lens with one filament of the light source focused on a hole 2mm in diameter in its center. The light passing through the hole was collimated

and then passed through a converging lens.

An episcotister disk chopped the beam of light at this nodal point. A collimator then directed the light onto a sheet of white translucent plastic. All elements of the optical system were placed on an optical bench.

The episcotister disk, 15" in diameter with three equal metal sectors, was attached to a variable speed motor controlled by a regulated power supply.

The disk was rotated through a beam of light produced by a small light with a photoresistor positioned in line with the bulb on the opposite side of the disk. The photoresistor was connected to a dual beam oscilloscope to monitor frequency (in flashes/second).

All of the apparatus was enclosed in a black wooden box (47" x 27" x 27") with the exception of the regulated power supply and the rheostat. A small hole (1.5 cm in diameter) was drilled at the point where the light from the light source fell upon the surface of the box. An iris diaphragm was bolted to the inside front of the box at this point with the white translucent plastic placed between the diaphragm and the box. The operation of the diaphragm was controlled externally and was used to block the light during the interstimulus and intertrial intervals.

A viewing chamber consisting of black bristol boards extending 17" from top, bottom, and two sides of the box was constructed to reduce the amount of stray illumination

reaching the S. An adjustable chin rest was placed at the edge of the viewing chamber with the distance between the stimulus light and the eye of the S being 15½". The visual angle subtended by the stimulus was 2° 10'.

The intensity of the light source was 3.40 millilamberts.

Procedure

All Ss were brought into the laboratory one day before the start of the experimental period and familiarized with the procedure. Eye dominance was determined at this time using the finger-pointing test.

The experimental period was 96 hours in duration with the CFF measured at 0, 3, 6, 9, 24, 48, 72, and 96 hours.

At the 0 hour testing session, the non-dominant eye of the MD and PC Ss was occluded by a black eye patch. A 15 minute dark adaptation followed while the S sat with his head supported by the chin rest. The C Ss were also dark adapted for 15 minutes although no eye patch was applied. Instead, the vision of the non-dominant eye was blocked by a mask positioned in front of the eye.

A descending method of limits was used, the CFF defined as the mean of eight descending trials. The stimulus was presented at an initial frequency well above fusion

(47.62 flashes/second) and the frequency was decreased by approximately 0.75 flashes/second on each succeeding presentation. The stimulus was presented for five seconds with the interstimulus interval being five seconds. Ss were instructed to fixate on the center of the stimulus and indicate the first appearance of flicker. There was a 45 second interval between each descending series.

After the 0 hour testing period, the black eye patch was secured to the non-dominant eye of the MD Ss who were asked not to remove it during the experimental period. The patch was checked at each test interval. Other than being cautioned about the operation of a vehicle during the experimental period and asked not to consume unusual quantities of alcohol, no further restrictions were placed on their activities.

The same testing procedure was followed for the remaining test sessions.

After the 96 hour test session, the black eye patch was removed from the non-dominant eye of the MD Ss. All Ss were questioned concerning their visual experiences during the experimental period at this time. In addition, the diaries kept by the subjects during the experimental period were collected at this time. This procedure was followed in subsequent monocular deprivation studies although only the MD Ss were interviewed and asked to record their visual experiences.

RESULTS

Figure 3 shows the mean change in the CFF from the 0 hour test for all three groups.

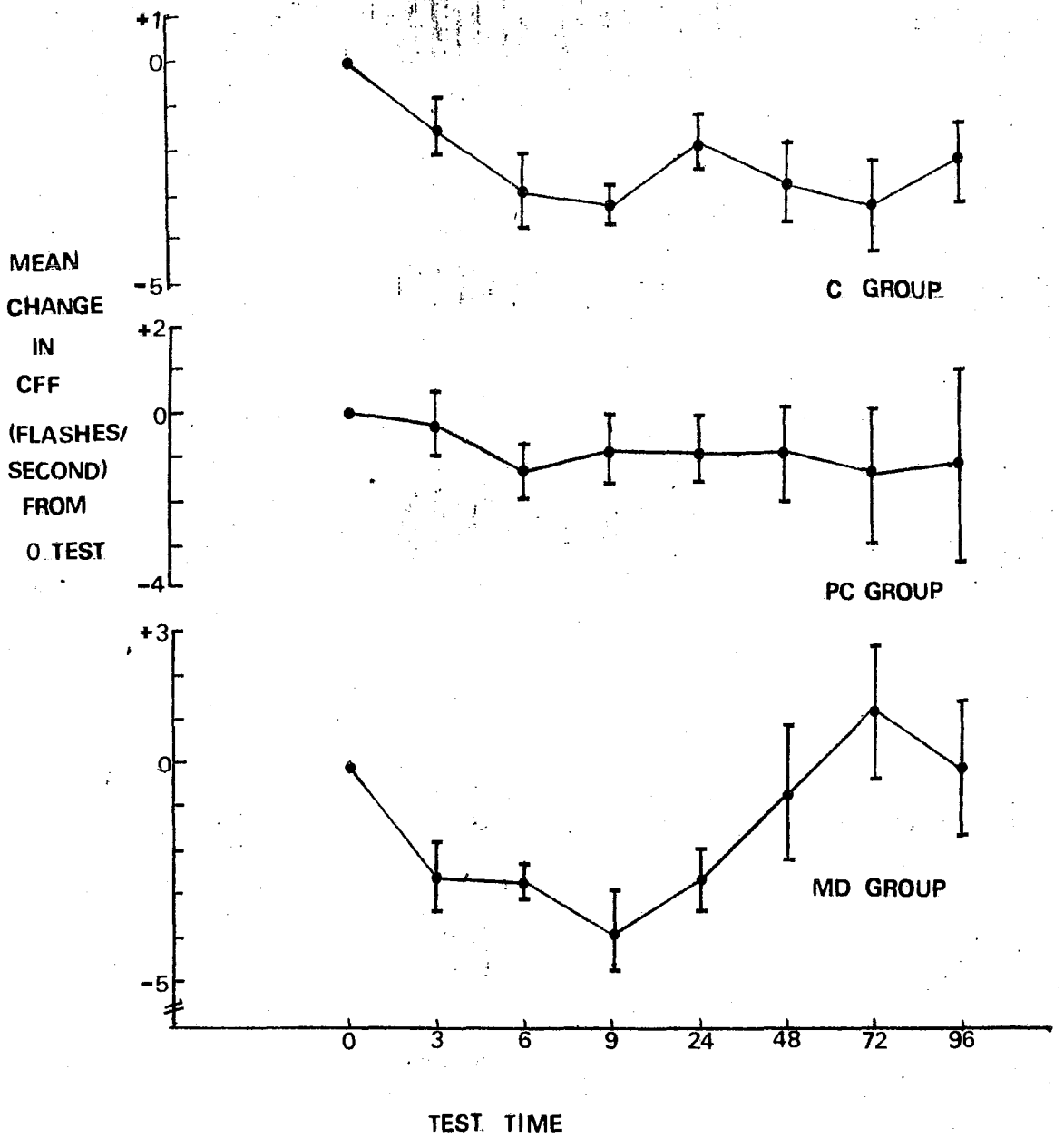
To determine if the three groups differed, an analysis of variance (two-factor mixed design) was performed on the difference scores between each test time and the 0 hour test (Table A, Appendix A). No significant conditions main effect was found although there was a significant trials main effect ($p<.05$) and a significant interaction effect ($p<.01$).

The Scheffé's tests (Table I) indicate that the CFF of the MD group was significantly enhanced compared to the PC and C groups at the 72 hour test. This enhancement is also present at the 48 and 96 hour tests when the MD group is compared to the C group. A significant depression of the CFF of the MD group occurs at the 3 and 9 hour tests compared to the PC group. The C group also showed a significant depression of the CFF at the 9 hour test when compared with the PC group.

COMMENT

These results suggest that there is a depression-enhancement effect in the MD condition when the three conditions are compared. This is consistent with the previous

Figure 3. Mean change in the CFF from the 0 hour test for the MD, PC, and C groups, Experiment I.


MEAN CHANGE IN CFF (FLASHES/ SECOND) FROM 0 TEST
+1
0
-5
C GROUP
+2
0
-4
PC GROUP
+3
0
-5
MD GROUP
0
3
6
9
24
48
72
96
TEST TIME

TEST TIME COMPARISON	3	6	9	24	48	72	96
MD vs PC	*	ns	*	ns	ns	*	ns
MD vs C	ns	ns	ns	ns	*	**	*
PC vs C	ns	ns	*	ns	ns	ns	ns

* $p < .05$
** $p < .01$

TABLE I. Scheffé's test comparing the MD, PC, and C groups in Experiment I. The comparisons were made on the changes in the CFF from the 0 hour test to the test time noted.

data (Zubek & Bross, 1972).

There are, however, some discrepancies. First, we find that the depression in the CFF is maximal at the 9 hour test rather than at the 6 hour test with the enhancement effect occurring at the 72 rather than at the 24 hour test. Further, while Bross and Zubek (1972) found a progressive increase in the CFF throughout deprivation, our results imply that the CFF returns to baseline after 96 hours. In addition, unlike Zubek and Bross (1972), the CFF in both the PC and C conditions is depressed over the entire experimental period.

The most striking aspect of the results, however, is the amount of variability in the data. Since it is difficult to interpret such unreliable data, we decided to repeat the experiment, making changes to reduce the variability. Experiment II, therefore, represents a further attempt to verify Zubek and Bross' (1972) results.

EXPERIMENT II

Several procedural changes were made in this experiment. First, the intensity of the light source was increased until the CFF approximated that of Zubek and Bross (1972). Second, a number of pretest sessions were introduced. Finally, the number of descending trials was reduced from eight to five trials as we had observed a fatigue effect in Experiment I within test sessions.

Four pilot Ss were given five trials each day for five consecutive days to determine if five pretests were sufficient to yield a reliable CFF. The light intensity was 6.79 millilamberts for the first two pilot Ss with this value increased to 27.03 millilamberts for the final two Ss. This latter intensity yielded values of the CFF similar to those reported by Zubek and Bross (1972). All Ss showed a reliable CFF by the end of the five day period.

METHOD

Five Ss were assigned to each of three groups - a MD, PC, and C group. All Ss were brought into the laboratory five days before the start of the experimental period and eye dominance determined. Each S was tested at the

same time each day. All Ss were tested between 9:30 AM and 1:30 PM.

After the fifth pretest session, MD and PC Ss were tested at intervals of 0, 3, 6, 9, 24, 48, 72, and 96 hours. The C Ss were given only the first five tests in the experimental period.

The testing procedure is the same as that outlined in Experiment I and was used in subsequent experiments.

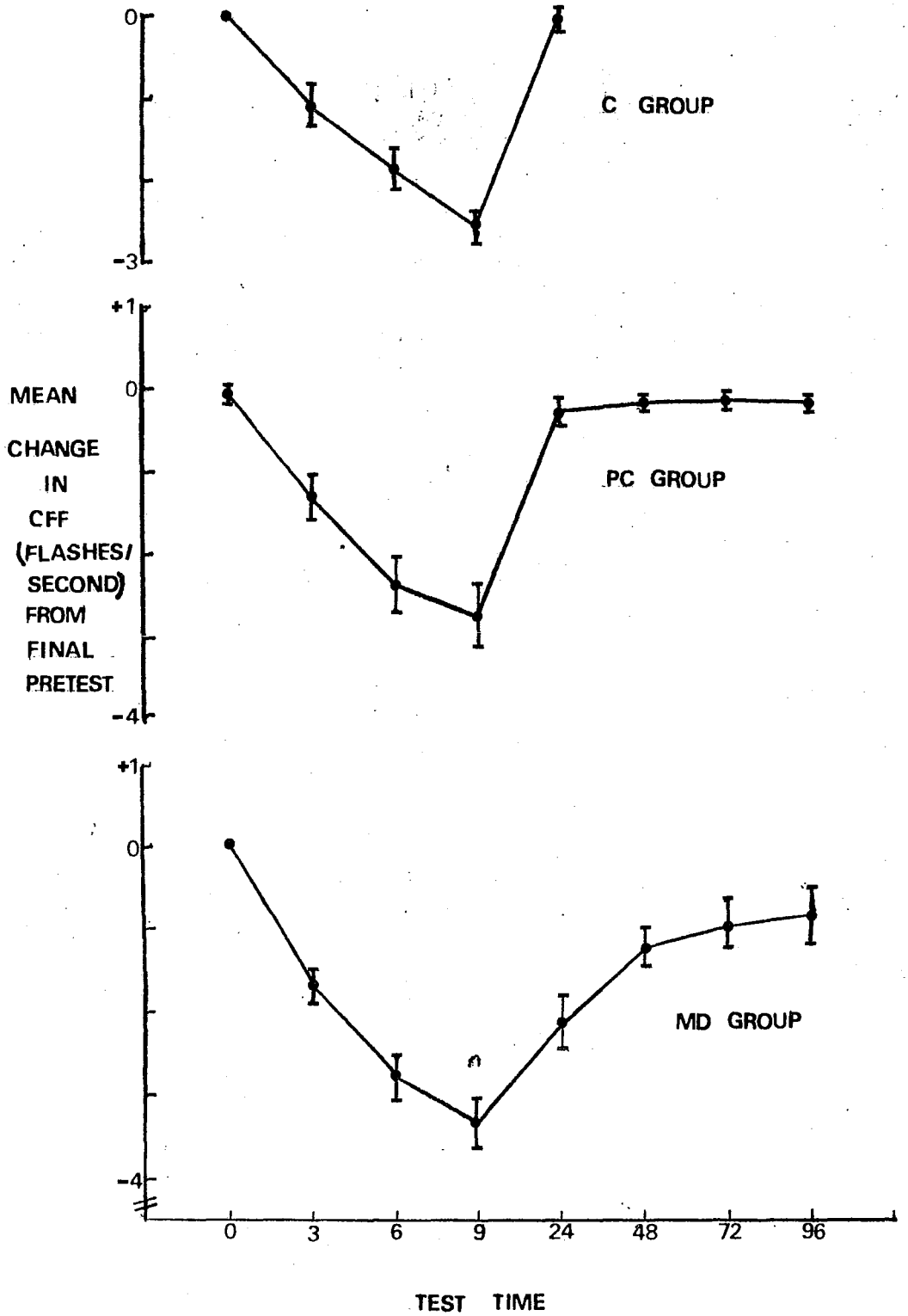
RESULTS

Figure 4 shows the mean changes in the CFF from the final pretest for the three conditions.

The analysis of variance comparing the performance of the three groups on the first day of the experimental period is shown in Table B (Appendix A). A significant conditions main effect was found ($p < .01$) as well as a significant trials main effect ($p < .001$) and a significant interaction ($p < .001$). The Scheffé's test (Table II) showed that the CFF of the MD group was more depressed than the C group at all test times except the 0 hour test and that the CFF of the MD group was significantly more depressed than that of the PC group at the 24 hour test.

To determine if the MD and PC groups differed over the entire experimental period, the data of the two groups were analyzed (See Table C, Appendix A). A significant con-

Figure 4. Mean change in the CFF from the final pretest for the MD, PC, and C groups, Experiment II.


0
-3
C GROUP
+1
0
-4
PC GROUP
MEAN CHANGE IN CFF (FLASHES/ SECOND) FROM FINAL PRETEST
+1
0
-4
MD GROUP
0
3
6
9
24
48
72
96
TEST TIME

TEST TIME / COMPARISON	0	3	6	9	24
MD vs PC	ns	ns	ns	ns	**
MD vs C	ns	*	**	*	**
PC vs C	ns	ns	ns	ns	ns

* $p < .05$

** $p < .01$

TABLE II. Scheffé's test comparing MD, PC, and C groups (Experiment II) at the 0, 3, 6, 9, and 24 hour tests.

ditions main effect ($p < .05$), trials main effect ($p < .001$), and interaction ($p < .001$) were found. The results of the Scheffé's test (Table III) indicate that the CFF of the MD group was significantly more depressed than that of the PC group at the 9, 24, 48, 72, and 96 hour tests.

COMMENT

The results indicate that, while there is a significant decline in the CFF in the MD group, a similar decline also occurs in the two control groups. The magnitude of the decline in the PC and C groups was not as great as in the MD condition, indicating that monocular deprivation does affect the CFF of the non-occluded eye. A further difference in the performance of the three groups occurs at the 24 hour test with the CFF of the PC and C groups returning to the baseline level while the CFF of the MD group remains significantly lower than the pre-deprivation level. This result indicates that monocular deprivation retards the rate at which the CFF returns to the baseline level after the initial depression with the process still not complete by the end of deprivation.

The decline in the CFF of all groups during the first day of the experimental period is puzzling in that Zubek and Bross (1972) found no decline in the control group. It is possible that repeated testing or the time of

TEST TIME / COMPARISON	0	3	6	9	24	48	72	96
MD vs PC	ns	ns	ns	*	**	**	**	**

* $p < .05$
** $p < .01$

TABLE III. Scheffé's tests comparing MD and PC groups (Experiment II) at the 0, 3, 6, 9, 24, 48, 72, 96 hour tests.

day at which testing occurs affects the CFF, producing a progressive decrease in the measure. There is some evidence to suggest that the monocular CFF varies with time of day (Tsushima, 1963; Walsh & Misiak, 1966), although this effect has not been isolated from the effects of repeated testing on the same day.

The second unusual aspect of the data is the failure to demonstrate any enhancement of the CFF in the MD condition. It is possible that repeated testing on the first day of deprivation prolongs the depression effect, perhaps masking an enhancement effect. Zubek and Bross (1972) did not find a prolonged depression effect, indicating that procedural differences are responsible for the differing results.

EXPERIMENT III

The purpose of Experiment III, then, was to determine whether any enhancement of the CFF of the non-occluded eye occurs during a four day period of monocular deprivation when testing occurs only at 24 hour intervals. Also, it was decided to determine whether any changes occur in the CFF of the occluded eye.

METHOD

Eight Ss, divided into a MD group (3 Ss) and a PC group (5 Ss), were brought into the laboratory for four consecutive days at the same time each day for the four pretest sessions. The Ss were instructed to return at the same time each day for the next five days (the experimental period).

Following the determination of the CFF of the dominant (non-occluded) eye at each test session, the eye patch was transferred to the dominant eye and the non-dominant (occluded) eye was tested after a five minute rest period.

RESULTS

The mean changes in the CFF of the non-occluded (dominant) and occluded (non-dominant) eyes from the final pretest are shown in Figures 5 and 6, respectively.

An analysis of variance was performed on the changes in the CFF for the non-occluded and occluded eyes of both groups (Tables D and E, Appendix A, respectively). No significant changes were found in either eye of the MD group compared to the PC group.

COMMENT

The results indicate that no enhancement of the CFF of the non-occluded eye occurs when testing is restricted to 24 hour intervals. This result indicates that the prolonged depression of the CFF of the MD group in Experiment II is due to repeated testing occurring on the first day of deprivation.

The results also show that no changes occur in the CFF of the occluded eye, a result consistent with the previous research (Bross & Zubek, 1972).

Figure 5. Mean change in the CFF of the non-occluded (dominant) eye from the final pretest for the MD and PC groups, Experiment III.

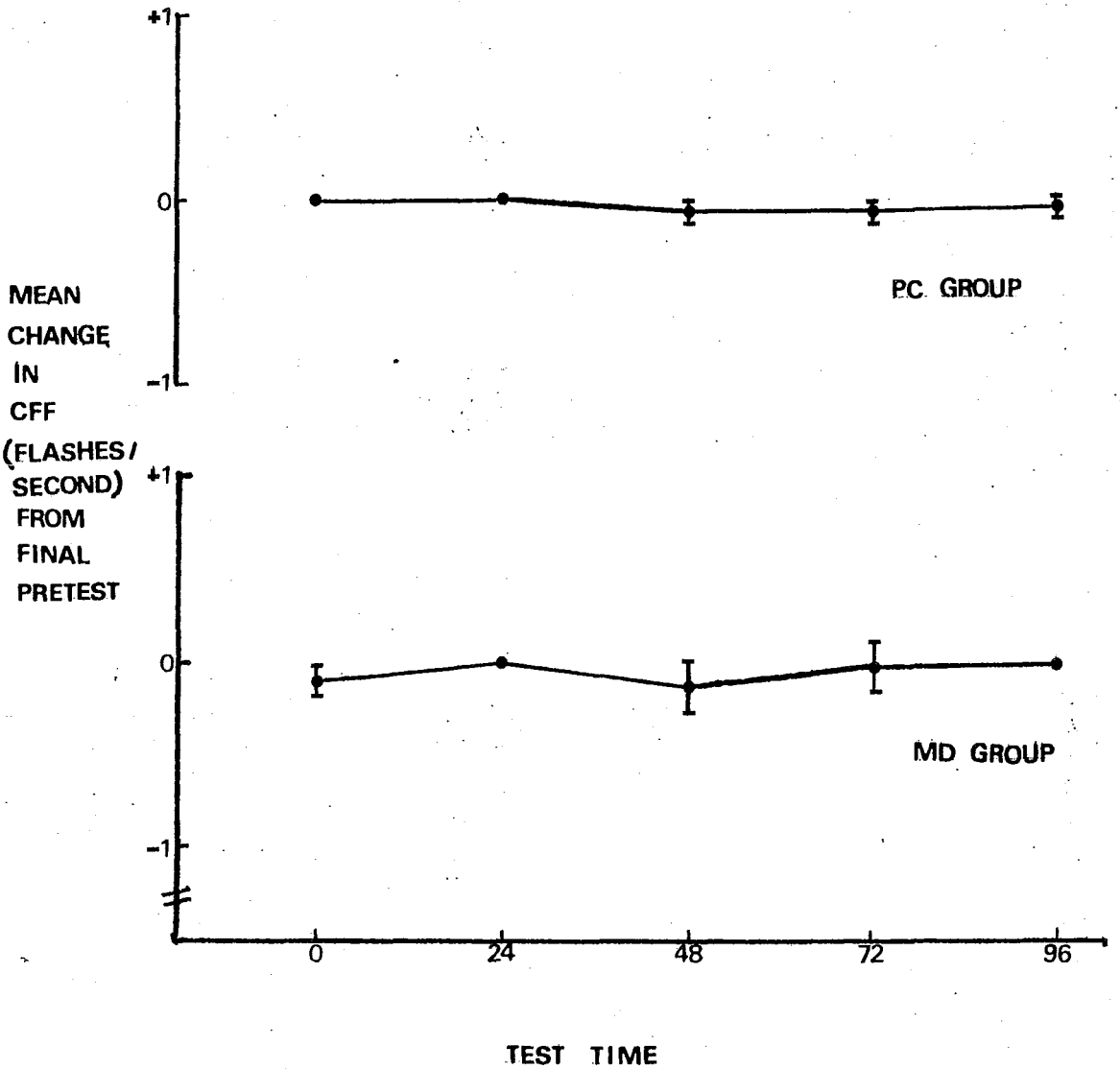
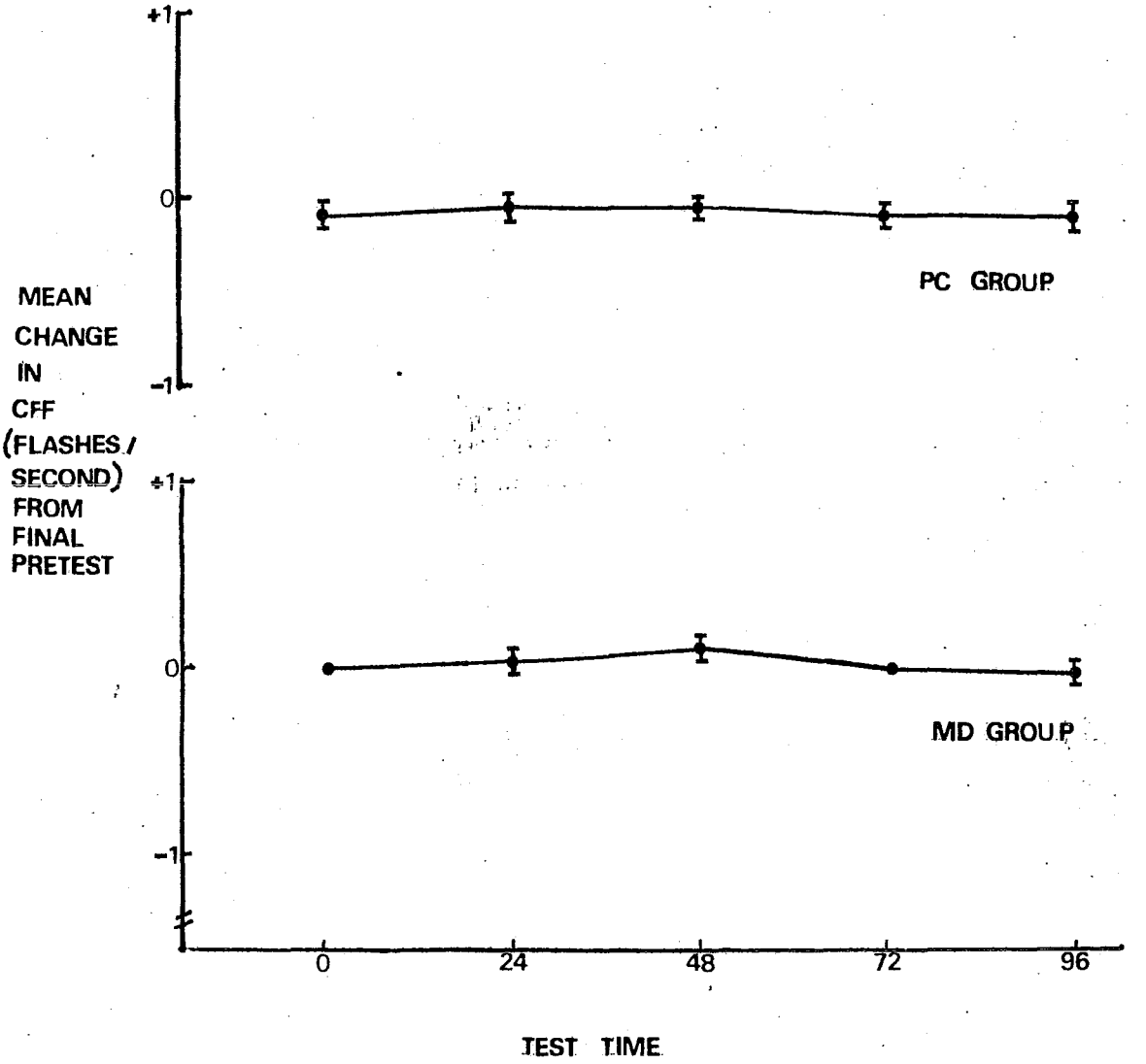

+1
0
-1
MEAN CHANGE IN CFF (FLASHES / SECOND) FROM FINAL PRETEST
PC GROUP
MD GROUP
0
24
48
72
96
TEST TIME

Figure 6. Mean change in the CFF of the occluded (non-dominant) eye from the final pretest for the MD and PC groups, Experiment III.


+1
0
-1
MEAN CHANGE IN CFF (FLASHES / SECOND) FROM FINAL PRETEST
PC GROUP
+1
0
-1
MD GROUP
0
24
48
72
96
TEST TIME

SUMMARY OF SUBJECTIVE EFFECTS

Tables IV and V indicate the most commonly reported effects of monocular deprivation on the occluded and non-occluded eyes respectively. Included in these tables are the reports of ten subjects monocularly deprived prior to the present investigation (Heron & Turkel, 1972). Table VI shows the alterations occurring in visual perception when the eye patch was removed at the end of the deprivation period. Only the reports of subjects from the present study have been included in the table. It can be seen that the most commonly reported effects of monocular deprivation on the occluded eye are phantom vision, patterns, and the appearance of flashing lights.

Phantom vision, the sensation of "seeing" with both eyes (Cohn, 1971), usually occurred in dim illumination, only three Ss noticing the effect under normal light conditions. The occurrence of phantom vision was not restricted to any specific stage of deprivation. Subject J.T. described the sensation as follows:

> "This feeling (of looking through the deprived eye) was sometimes so strong that I felt compelled to feel the eye patch with my hand to make sure it was still in place."

During the first two days of deprivation, several Ss experienced white (occasionally green or purple) lines

PHANTOM VISION	FLASHES OF LIGHT & DARK	PATTERNS
14	5	13

TABLE IV Subjective effects of monocular deprivation on the occluded eye (n=23).

FADING	DEPTH DISTORTION
21	23

TABLE V. Subjective effects of monocular deprivation on the non-occluded eye (n=23).

DIFFERENCE IN BRIGHTNESS	DEPTH DISTORTION	VISION CLEARER IN OCCLUDED EYE	VERTIGO	FOCUSING DIFFICUTLY
13	8	12	6	4

TABLE VI. Subject effects of eye patch removal (n=13).

moving across a dark field. Subject L.K. described the patterns as consisting of "little white worms floating around in the air." Only three subjects reported any increase in the complexity of these patterns over time.

Finally, some subjects reported occasional bright flashes of light "jumping in front of the occluded eye" as subject I.D. reported. This sensation was restricted to the final stages of deprivation in all but one subject.

As might be expected, difficulty in judging the distance of objects was reported by all Ss from the time the eye patch was applied. Depth perception was still disturbed in the final stages of deprivation, although most Ss reported less difficulty. While depth perception was distorted, all Ss reported that objects viewed appeared three-dimensional.

One peculiar effect which was almost universally reported (21 out of 23 Ss) was the disappearance of fixated objects in the non-occluded eye. This fading was present on the first day of deprivation and persisted for the entire deprivation period. Subject J.S. described the fading as follows:

> "When I look at something for a while (a scene or printing in a book), the central part of my visual field seems to disappear into a shapeless grey mass."

The fading was particularly noticeable in the temporal visual field, no S reporting fading as restricted to only the

nasal visual field. All Ss reported that the fading was eliminated by concentration and did not interfere with the testing sessions. There was no apparent correlation between illumination levels and the frequency of fading.

The effects of the removal of the eye patch are of relatively brief duration, normal visual perception generally present within one-half hour of unpatching. All Ss reported that objects viewed with the previously occluded eye appeared brighter than when viewed with the non-occluded eye. A distortion in depth perception was noted by several Ss and 75% of these also experienced vertigo. All but one S reported that vision in the previously occluded eye was clearer than in the non-occluded eye.

EXPERIMENTS ON CIRCADIAN INFLUENCES

EXPERIMENT IV

We now turn to the question of whether the depression of the CFF found in all groups in Experiment II is due to circadian influences. There have been suggestions in the literature that the CFF does exhibit circadian variations. Hammer (1951) found that the CFF increased between 8:00 AM and 11:00 AM, decreased by 1:00 PM, and increased again at 4:00 PM. Similar results were obtained by Tsushima (1963) although a progressive decline of the CFF occurred following the 11:00 AM test. Musumeci and Misiak (1974) found that the CFF increased between 9:00 AM and Noon, decreased at 3:00 PM, increased slightly at 6:00 PM, and then decreased again by 9:00 PM. Different results were obtained by Walsh and Misiak (1966) who, using a large group of subjects, found three distinct response patterns when the CFF was tested at three hour intervals during a 12 hour period. The subjects either showed an increase in the CFF, a decrease in the CFF, or no change.

The evidence for circadian fluctuations in the CFF is thus far from clear and any conclusion based on the literature can only be tentative. Further, in all of these

experiments the influence of the time of day is confounded with the effects of repeated testing. To avoid this difficulty, a paradigm in which subjects were tested once a day but at different times was used.

METHOD

Five Ss were brought into the laboratory for four consecutive days at the same time each day for the four pretest sessions. This time (0 hour) varied for different Ss but all Ss were tested between 10:30 AM and 1:00 PM.

The Ss were then tested once a day for the next six days. The sequence of test times was 0 plus three hours, 0, 0 plus six hours, 0, 0 plus nine hours, and 0 hour. The CFF was determined using the procedure outlined previously.

RESULTS

Figure 7 shows the performance of each subject at all test times. The mean change in the CFF from the final pretest at each test session is shown in Figure 8. A comparison of the three groups in Experiment II and the group from Experiment IV at the 3, 6, and 9 hour tests is shown in Figure 9.

The analysis of the difference scores between the 3, 6, and 9 hour tests and the final pretest reveals a sig-

Figure 7. Changes in the CFF of the dominant eye of individual subjects in Experiment IV over a nine hour period. The first four tests represent the pretest sessions.

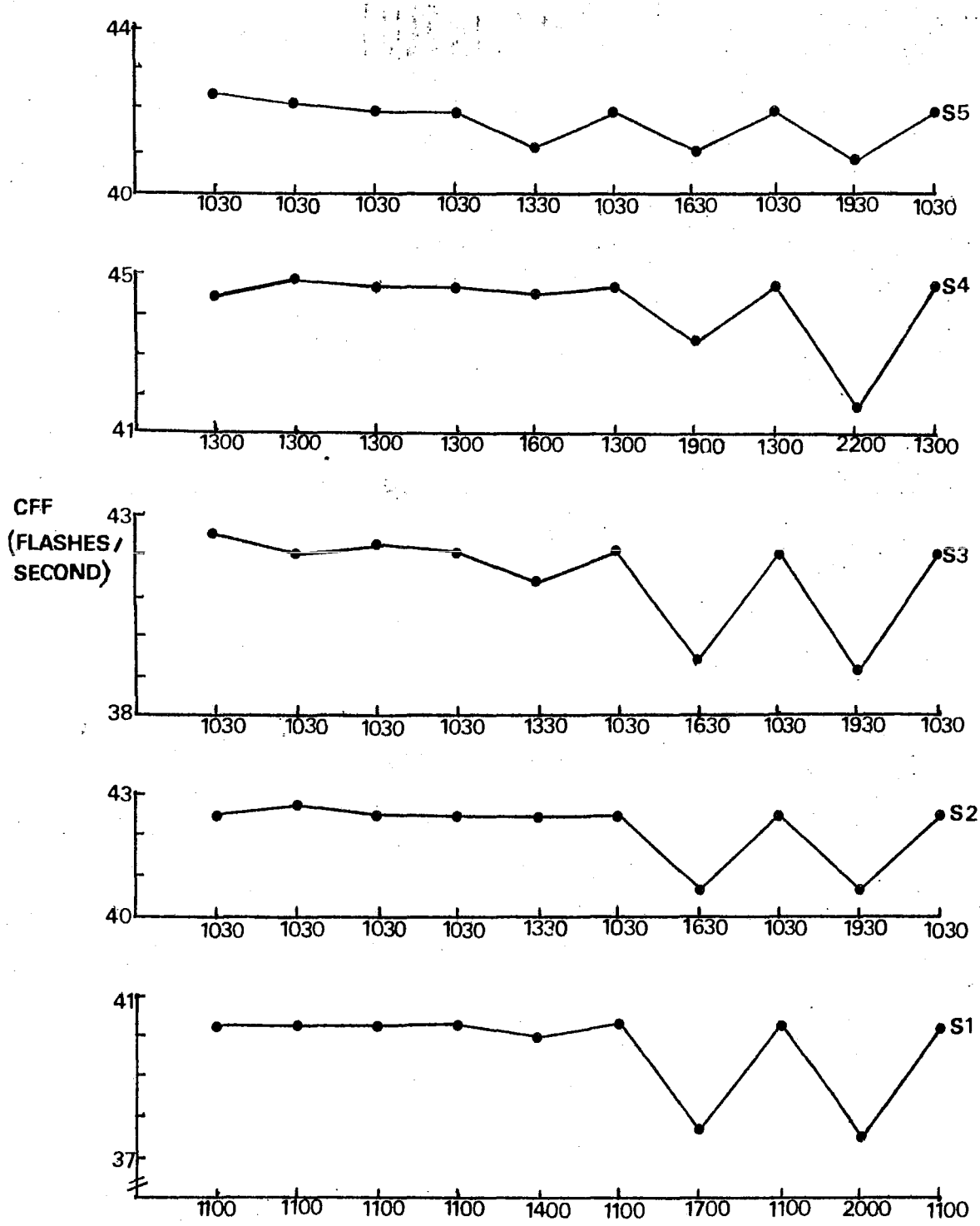

44
40
1030 1030 1030 1030 1330 1030 1630 1030 1930 1030
S5
45
41
1300 1300 1300 1300 1600 1300 1900 1300 2200 1300
S4
CFF
(FLASHES /
SECOND)
43
38
1030 1030 1030 1030 1330 1030 1630 1030 1930 1030
S3
43
40
1030 1030 1030 1030 1330 1030 1630 1030 1930 1030
S2
41
37
1100 1100 1100 1100 1400 1100 1700 1100 2000 1100
S1
TEST TIME

Figure 8. Mean change in the CFF of the dominant eye from the final pretest over a nine hour period (Experiment IV).

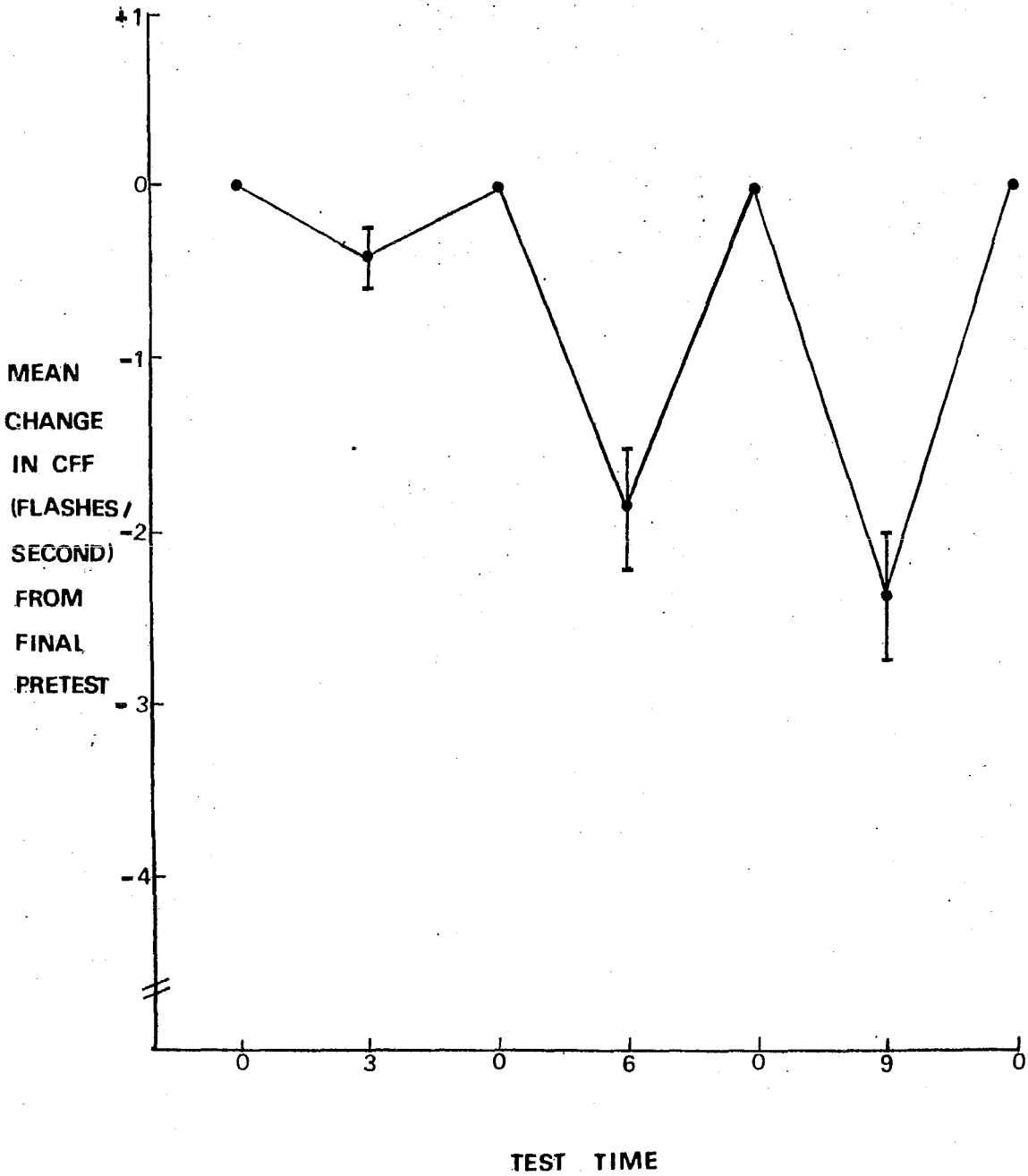
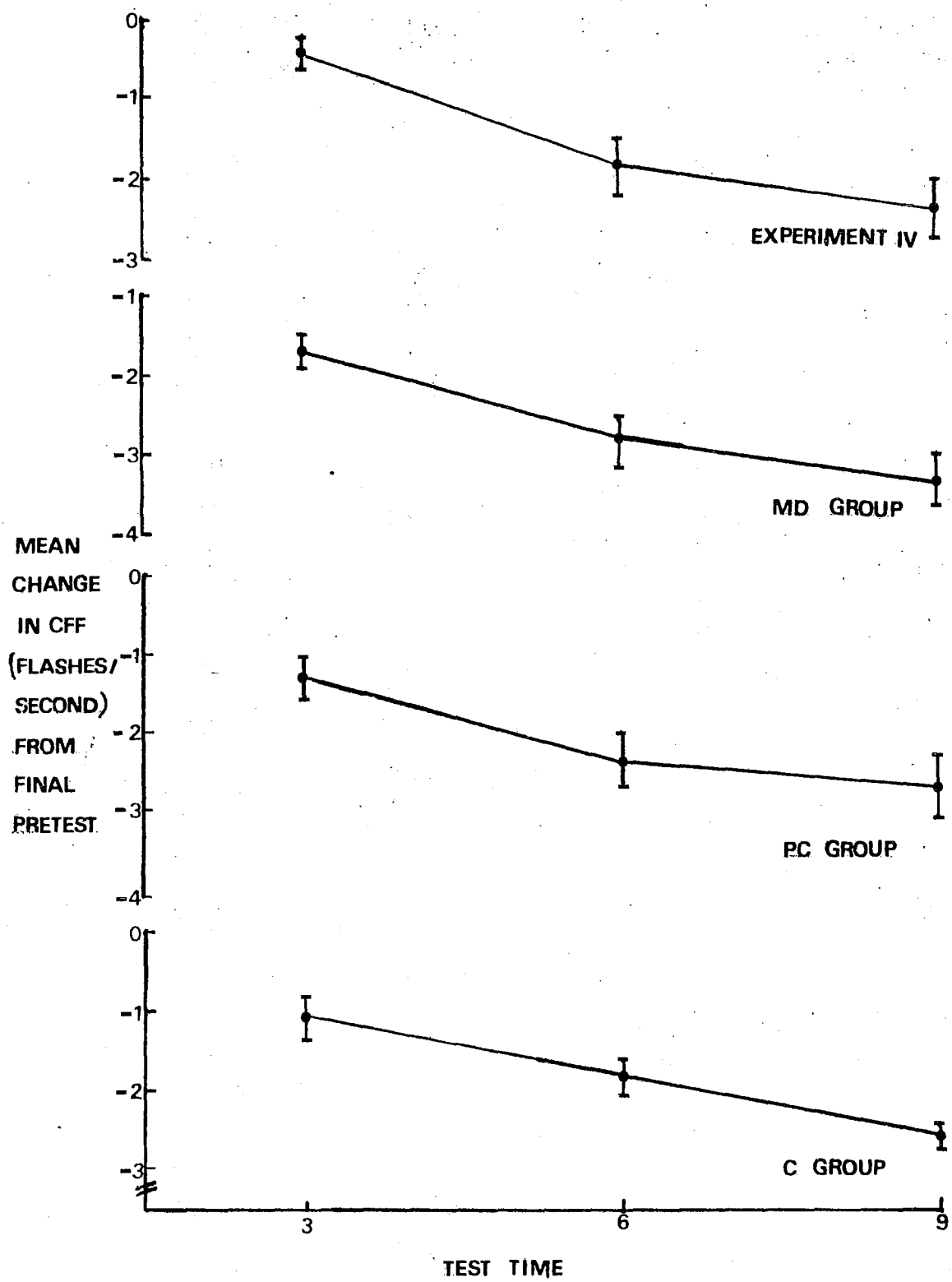

+1
0
-1
-2
-3
-4
MEAN CHANGE IN CFF (FLASHES / SECOND) FROM FINAL PRETEST
0
3
0
6
0
9
0
TEST TIME

Figure 9. Mean change in the CFF of the non-occluded (dominant) eye from the final pretest for the MD, PC, and C groups (Experiment II) and the nine hour condition in Experiment IV at the 3, 6, and 9 hour tests.


EXPERIMENT IV
MD GROUP
PC GROUP
C GROUP
MEAN CHANGE IN CFF (FLASHES/SECOND) FROM FINAL PRETEST
0
-1
-2
-3
-4
3
6
9
TEST TIME

nificant change in the CFF over trials ($p < .001$) (See Table F, Appendix A). Table VII shows the results of the Scheffé's test. The CFF at the 6 and 9 hour tests was significantly depressed compared to the final pretest and the 3 hour test. There was no significant difference between the final pretest and the 3 hour test.

The analysis of variance comparing the changes in the CFF from the final pretest for the three groups in Experiment II and the group in Experiment IV at the 3, 6, and 9 hour tests (Table G, Appendix A) reveals a significant conditions main effect ($p < .05$) and a significant trials main effect ($p < .001$). The interaction effect was not statistically significant. Scheffé's tests (Table VIII) indicate that the CFF of the MD group was more depressed than that of the group in Experiment IV at all test times. The CFF of the PC group was also significantly more depressed than that of the group in Experiment IV at the 3 hour test.

As most of the Ss in the experiment had the 0 hour around mid-day, it was decided to repeat the experiment with two Ss having the 0 hour at 9:00 AM and three with the 0 hour at 3:00 PM. It was also decided to use a 15 rather than a 9 hour interval to find out more about the pattern of CFF changes.

Following the four pretest sessions, the Ss were instructed to return each day with the test time varied from day to day. All Ss were tested at 9:00 AM, 12:00 Noon, 3:00

TEST TIMES	0	3	6	9
0	-	ns	**	**
3	-	-	**	**
6	-	-	-	ns
9	-	-	-	-

** $p < .01$

TABLE VII. Scheffé's tests comparing changes from final pretest (0 hour) for each set of tests for the nine hour condition, Experiment IV.

COMPARISON \ TEST TIME	3	6	9
MD vs PC	ns	ns	ns
MD vs C	ns	*	ns
PC vs C	ns	ns	ns
EXP IV vs MD	**	*	*
EXP IV vs PC	*	ns	ns
EXP IV vs C	ns	ns	ns

* $p < .05$
** $p < .01$

TABLE VIII. Scheffé's test comparing change in CFF from final pretest for all groups in Experiment II and the nine hour condition in Experiment IV at the 3, 6, and 9 hour tests.

PM, 6:00 PM, 9:00 PM, and 12:00 Midnight. To ensure that the baseline measure was stable, all Ss were tested twice at the 0 hour during the experimental period. The sequence of test times was randomly varied for each S to eliminate order effects.

RESULTS

The graphs of individual S's performance at all test times (including pretests) are shown in Figure 10. Figure 11 shows the individual subject graphs over a 15 hour period with the pretest sessions excluded. The mean change in the CFF between each test time and the 12:00 Noon test is shown in Figure 12.

The results of the analysis of variance of the difference scores between each test time and the 12:00 Noon test time indicate that the change in the CFF over trials was significant ($p < .001$) (See Table H, Appendix A). From the Scheffé's test (Table IX) it can be seen that the CFF at the 9:00 AM test was significantly elevated compared to the 6:00 PM, 9:00 PM, and 12:00 Midnight test times. The CFF at the 12:00 Noon test time was significantly greater than that of all other test times with the exception of the 9:00 AM test. At the 3:00 PM test the CFF was significantly greater than at later test times. The only other change which was statistically significant was the decline in the

Figure 10. Changes in the CFF of the dominant eye of individual Ss in the 15 hour condition in Experiment IV. The first four tests represent the pretest sessions.

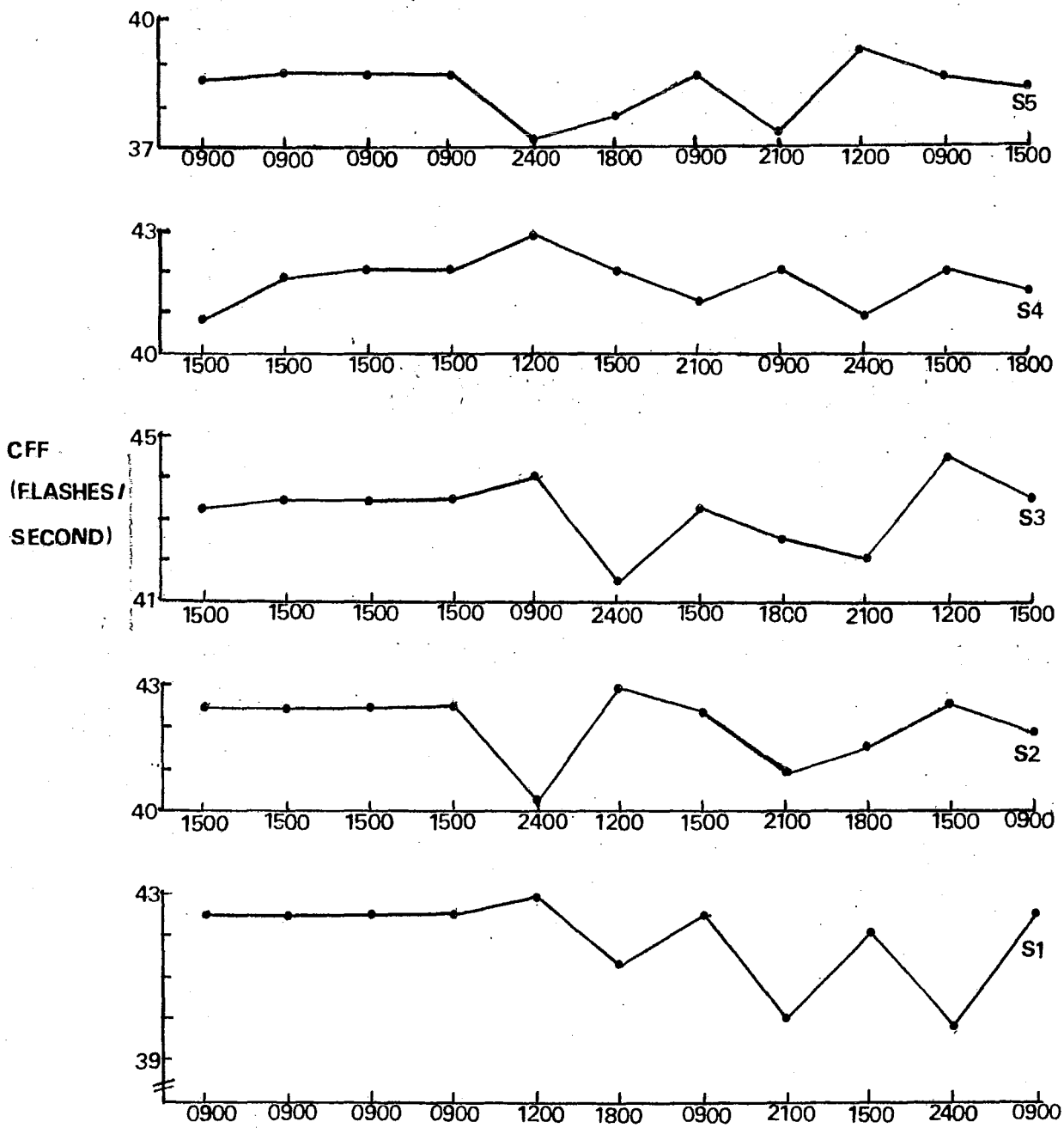

40
37
0900 0900 0900 0900 2400 1800 0900 2100 1200 0900 1500
S5
43
40
1500 1500 1500 1500 1200 1500 2100 0900 2400 1500 1800
S4
CFF
(FLASHES/
SECOND)
45
41
1500 1500 1500 1500 0900 2400 1500 1800 2100 1200 1500
S3
43
40
1500 1500 1500 1500 2400 1200 1500 2100 1800 1500 0900
S2
43
39
0900 0900 0900 0900 1200 1800 0900 2100 1500 2400 0900
S1
TEST TIME

Figure 11. Temporal changes in the CFF of the dominant eye of individual Ss in the 15 hour condition in Experiment IV.

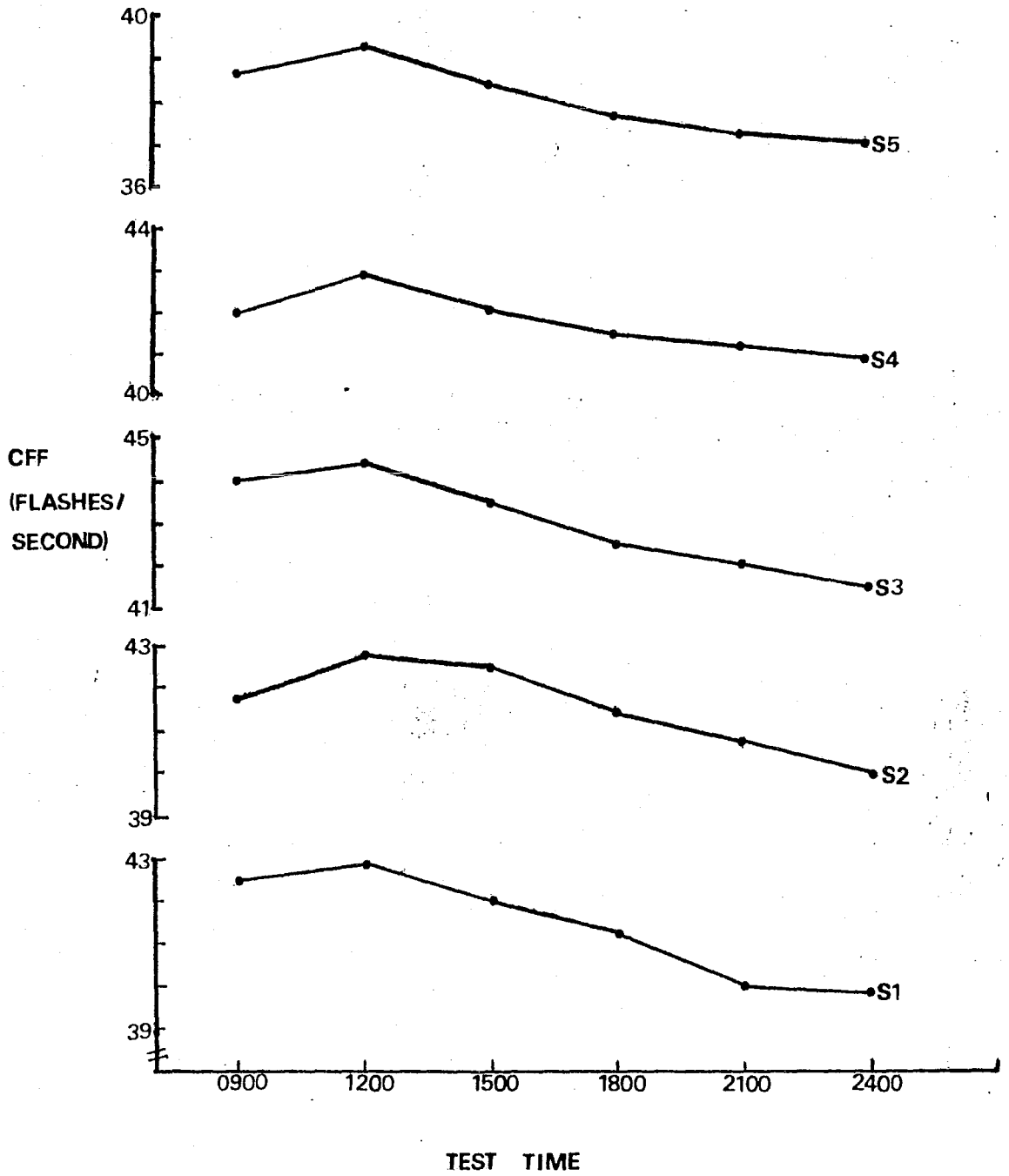
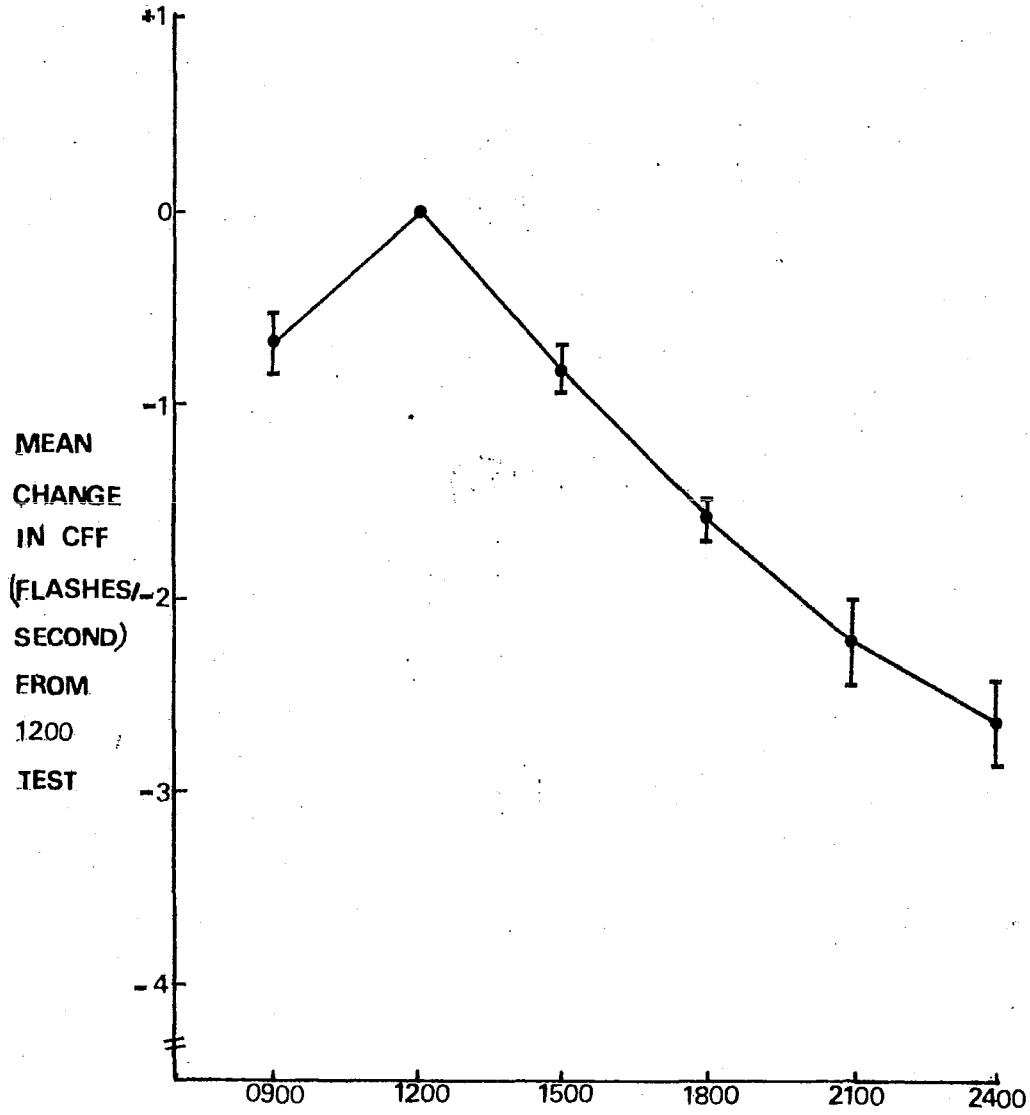

40
36
S5
44
40
S4
45
41
S3
43
39
S2
43
39
S1
CFF
(FLASHES/
SECOND)
0900
1200
1500
1800
2100
2400
TEST TIME

Figure 12. Mean change in CFF of dominant eye from the 1200 hr test for the 15 hour condition in Experiment IV.


+1
0
-1
-2
-3
-4
MEAN CHANGE IN CFF (FLASHES/SECOND) FROM 1200 TEST
0900
1200
1500
1800
2100
2400
TEST TIME

TEST TIMES	0900	1200	1500	1800	2100	2400
0900	-	ns	ns	*	**	**
1200	-	-	**	**	**	**
1500	-	-	-	*	**	**
1800	-	-	-	-	ns	**
2100	-	-	-	-	-	ns
2400	-	-	-	-	-	-

* $p < .05$
** $p < .01$

TABLE IX. Scheffé's tests comparing the change from the 1200hr test for each set of test times in the 15 hour condition, Experiment IV.

CFF from 6:00 PM to 12:00 Midnight.

COMMENT

The results support the findings of Tsushima (1963) in that there is an increase in the CFF between 9:00 AM and Noon with a progressive decline in the CFF occurring during the afternoon and evening.

The results are also valuable in that they reveal that monocular deprivation does produce a significant depression in the CFF even when the time of day at which testing occurs is considered. Repeated testing also appears to have a slight effect (found by comparing the PC group and the group from Experiment IV) although this effect is only statistically significant at the 3 hour test.

DISCUSSION

EXPERIMENTAL DATA

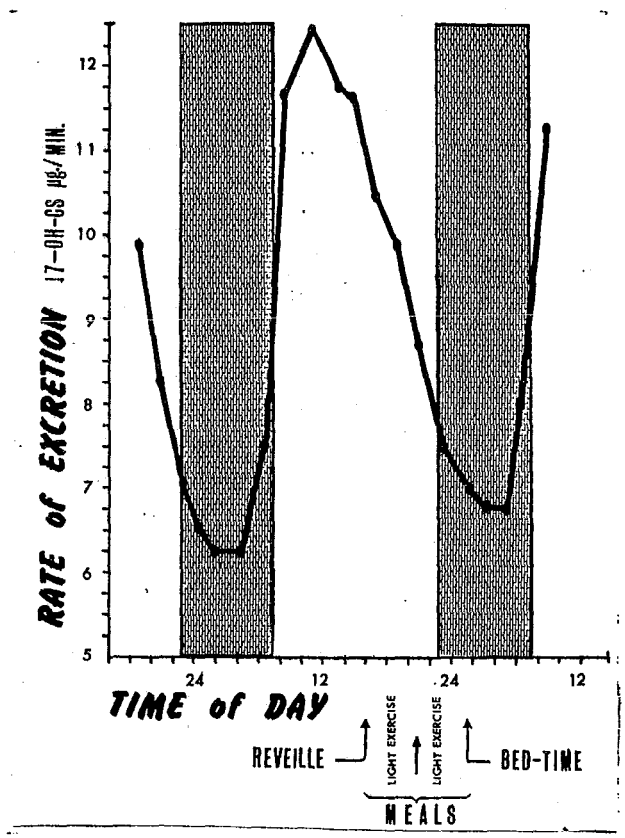
One obvious question raised by the present study is the basis for the circadian fluctuations in the CFF. While several experiments have investigated possible circadian variations in performance on perceptual tasks other than the CFF (Lavie, Lord, & Frank, 1974; Neuberger & Schmid, 1962, cited in Ward, 1964; Henkin, cited in Luce, 1970; Harris & Myers, 1954; Ward, 1964; Henkin, 1974), there has been little attempt to determine possible factors underlying the observed changes. Henkin (1974), however, has suggested that the circadian fluctuations in auditory, olfactory, and gustatory sensitivity may be due to fluctuations in the amount of cortisol secreted by the adrenal cortex, sensitivity being greatest when cortisol secretion is minimal. While the data is only correlational, it is possible that this substance may also be relevant to the observed changes in the CFF.

If is assumed that the circadian variations in the CFF are dependent on changes in some other factor, the proposed factor must fulfill two criteria. First, a similar (or inverse) pattern of fluctuations should be observed in

both the CFF and the proposed factor. This means that a peak (or trough) should occur in the underlying factor in the morning or at mid-day with a trough (or peak) occurring in the late evening or early morning. As it is possible that there is an interval between a change in the underlying factor and the effect on the CFF, it is not strictly necessary that the circadian rhythms be exactly superimposed. Further, if the proposed underlying factor was known to affect sensory functioning, this would provide further support for the possible relevance of the factor in producing circadian fluctuations in the CFF.

Nevertheless, there is evidence to suggest that substances secreted by the adrenal cortex may be relevant to the changes in the CFF. The secretion of cortisol from the adrenal cortex is maximal in the morning and minimal in the late evening (Nichols & Tyler, 1967). Plasma concentrations of 17-hydroxycorticosteroids (17-OHCS), metabolites of cortisol, show similar circadian fluctuations (Migeon, Tyler, Mahoney, Florentin, Castle, Bliss, & Samuels, 1956; Doe, Flink, & Goodsell, 1956; Perkoff, Eik-ness, Nugent, Fred, Nimer, Rush, Samuels, & Tyler, 1959; Doe, Vennes, & Flink, 1960; Orth, Island, & Liddle, 1967) as do urinary concentrations of 17-OHCS (Migeon et al., 1956; Doe et al., 1956; Doe et al., 1960; Bartter & Delea, 1962). Figure 13 shows the change in urinary 17-OHCS during a 24 hour period. Further support for a morning peak in adrenocortical activi-

Figure 13. Rate of excretion of 17-hydroxycorticosteroids (17-OHCS) during 24 hour intervals. (From Symington, 1969).


RATE of EXCRETION 17-OH-CS µg/MIN.
12
11
10
9
8
7
6
5
24
12
24
12
TIME of DAY
REVEILLE
LIGHT EXERCISE
LIGHT EXERCISE
BED-TIME
MEALS

ty is provided by the circadian fluctuations in the secretion of aldosterone and 17-ketosteroids (Bartter & Delea, 1962) and the secretion of epiandosterone and androsterone (Laatikainen & Vihko, 1968). The secretion of adrenocorticotrophic hormone (ACTH) from the anterior pituitary also exhibits similar circadian fluctuations (Symington, 1969). It is generally assumed that fluctuations in ACTH secretion underly the observed changes in adrenocortical activity, an assumption supported by the positive correlation existing between plasma concentrations of ACTH and plasma concentrations of 17-OHCS (Ney, Shimizu, Nicholson, Island, & Liddle, 1963).

While the circadian variations in ACTH secretion and the secretion of products by the adrenal cortex closely parallel those of the CFF, the conclusions drawn can only be tentative as the data is correlational. However, if there is evidence to suggest that one of the products affects sensory functioning, the case would be strengthened.

Henkin, Daly, and Ojemann (1966) have found that, in untreated patients suffering from adrenocortical insufficiency (ACI), auditory detection thresholds are significantly lower than normal and the ability to integrate auditory stimuli severely reduced. Treatment with carbohydrate-active steroids (CAS), a product of the adrenal cortex, resulted in a return of normal perceptual functioning. Their findings have been confirmed in later experiments (Henkin,

McGlone, Daly, & Bartter, 1967; Henkin & Daly, 1968) and suggest that CAS impair detection thresholds but facilitate performance on tasks requiring an integration of sensory stimuli.

The administration of CAS also increases the abnormally low olfactory and gustatory thresholds shown by ACI patients (Henkin & Bartter, 1966; Henkin, Gill & Bartter, 1963). The return of these thresholds to normal levels is not dependent on specific CAS as similar results have been obtained using prednisolone, cortisone, dexamethasone, and hydrocortisone (Henkin, 1970).

While it appears that CAS can alter sensory detection and integration, the reason for the effect is not clear. Henkin et al. (1966) have found that peripheral nerve conduction velocities in untreated ACI patients is 25% greater than in normal subjects. Conduction across the myoneural junction, however, is significantly slower than normal (Henkin & Daly, 1968). Administration of CAS restores normal conduction velocities, a result which suggests that CAS exert their effect on sensory functioning through altering nervous excitability. The manner in which CAS affect conduction velocities is not clear, however. Henkin and Daly (1968) and Henkin (1970) suggest that changes in the electrolytic balance are not responsible for the changes in conduction velocities or sensory functioning following the administration of CAS. Administration of deoxycortico-

steroid acetate, a sodium-potassium-active steroid, corrects the abnormal electrolytic balance in cases of ACI but does not alter sensory thresholds or conduction velocities. Sensory thresholds are only affected when CAS (which have little, if any, influence on sodium-potassium activity) are administered. It has been suggested (Nordin, 1964) that CAS may interfere with calcium metabolism and in this way may alter neural conduction although the nature of the interference is obscure. There is also evidence to suggest that dexamethasone (one of the CAS) may alter the regulatory mechanisms of the sodium pump, thereby altering the transmission of neural signals (Schade & van Wilgenburg, 1973). It is not known, however, if this effect is restricted to CAS or whether sodium-potassium-active steroids can also affect the pump mechanism.

However, whatever the mechanism, since CAS affect the integration of sensory stimuli and since the CFF presumably involves such an integration, one might expect a direct relation between the CFF and the level of CAS present.

It is now necessary to examine the results of the present study and those of the Manitoba studies to determine whether the proposed action of CAS can account for the results obtained. In addition, it is necessary to determine whether this hormonal account can provide an explanation for the differences in the results of the two sets of studies.

The results of the present study are compatible with this account of the interaction between hormonal systems and the central nervous system (CNS). In Experiment II, the decline in the CFF of all groups conforms to the notion that the CFF varies directly with the amount of CAS secreted. The gradual return of the MD group to baseline performance may simply be a result of frequent testing on the first day of deprivation, an explanation supported by the results of Experiment III. It would appear that monocular deprivation has a slight effect on the CFF as the decline in the MD group is significantly greater than that of the C group in Experiment II and the group in Experiment IV. However, when compared to the PC group, the MD group does not show a significantly greater decline in the CFF although there is a trend in this direction. It is possible that frequent testing, in conjunction with deprivation, is responsible for the greater depression in the CFF of the MD group. In Experiment III, no change in either eye would be expected as testing is restricted to 24 hour intervals and the level of CAS would be approximately equal at all test times. The results of Experiment IV are consistent with the notion that the level of CAS present influences temporal acuity as the circadian rhythms of both factors are similar.

It is possible to interpret the depression-enhancement phenomenon found by Zubek and Bross (1922) in terms of the possible influence of CAS on the CFF. The pituitary-

adrenocortical axis is extremely sensitive to conditions of stress, the secretory activity being altered in these situations (Liddle, 1971). If monocular deprivation, in conjunction with confinement, constitutes a stressful situation, then the observed changes in the CFF may be a result of altered ACTH secretion and adrenocortical activity. While the results of the present study and those of Tsushima (1963) suggest that the CFF should increase between 9:00 AM and Noon, the decline in the CFF found by Zubek and Bross (1972) between these times may be due to a disruption of the circadian rhythm of ACTH secretion and adrenocortical activity caused by stress (Liddle, 1971). It is also possible that the discrepant result is due to differences in the ACTH and adrenocortical rhythms of the subjects used.

The enhancement in the CFF may also be due to changes in the secretion of CAS as it has been reported (Liddle, 1971) that the secretion of ACTH by the anterior pituitary is markedly increased in stressful conditions, thereby elevating adrenocortical activity. With increasing durations of deprivation and confinement, ACTH secretion could increase, causing a resultant increase in the level of CAS present and, consequently, a progressive increase in the CFF. The plateaus occurring in the level of the CFF during prolonged deprivation (Zubek & Bross, 1973a) may represent the temporary adoption of an elevated, homeostatic level of ACTH secretion. Following deprivation, there would be a gradual

reduction in the level of CAS resulting in a gradual return of the CFF to pre-deprivation levels.

The interpretations, however, seem somewhat strained. Further, there are two ways in which the results are irreconcilable with the hormonal explanation unless it is assumed that slight differences in methodology (i.e., the establishment of stable baseline measures) are responsible. It is difficult to understand, for example, why the Manitoba studies fail to find any changes in the occluded eye. If the CFF is dependent on the level of CAS present, then it would be expected that the CFF of the occluded eye would exhibit changes similar to those observed in the non-occluded eye. Further, a decline in the CFF of the control subjects would be expected. The failure to demonstrate this effect in the Manitoba studies is puzzling as the circadian fluctuation of the CFF seems to be a strong effect.

In summary, the results of the present study suggest that the depression in the CFF found by Zubek and Bross (1972) is primarily due to circadian fluctuations in the CFF. Monocular deprivation does, however, accentuate the progressive decline in the CFF occurring during the day. Unlike Bross and Zubek (1972), we found no evidence to suggest that monocular deprivation causes an enhancement of the CFF in the non-occluded eye. The failure to observe any changes in the CFF of the occluded eye is consistent with the results of Bross and Zubek (1972). The failure to

confirm the depression-enhancement phenomenon outlined by Zubek (1972) suggests that the phenomenon is dependent on the methodology used, indicating that the effect is not a robust one.

The present research is important in that it indicates the role of methodology in producing the phenomenon outlined by Zubek (1972). In addition it provides the first conclusive evidence that circadian changes in the CFF do occur. This finding has broad implications for future research on perceptual functioning in which testing occurs at different times during the day. A great deal of research is needed to determine those aspects of sensory or perceptual functioning which show circadian variations as well as possible mechanisms underlying such variations. By determining these mechanisms, a clearer understanding of sensory functioning will be gained.

SUBJECTIVE DATA

While we have failed to confirm that monocular deprivation has large effects on the CFF, the subjective reports of monocularly-deprived subjects suggest that major changes are occurring in visual functioning. The subjective reports of these subjects, while unsupported by objective tests, cannot be ignored as these spontaneous observations as well as the questionnaire responses are so similar across subjects.

While it is obvious that any interpretation in terms of CNS function must necessarily be highly speculative, it is tempting to see whether the reports can be interpreted in terms of what is known about the visual system.

From the present reports it is evident that phantom vision, the sensation of "seeing" through the patch, is not due to irritative factors as suggested by Cohn (1971) but also occurs when no light falls upon an intact retina. While the physiological mechanisms underlying the occurrence of this phenomenon are not clear, it is possible that the activation of cell assemblies is involved (Hebb, 1949). With synchronous visual input, cell assemblies may be formed in those areas of the visual system served by each eye. Repeated, simultaneous activation of these units may result in connections being formed between the units. Under conditions of monocular deprivation, the viewing of familiar stimulus patterns could activate the unit normally activated by the deprived eye so that the subject has the impression that he has binocular vision. It can also be suggested that, under conditions of dim illumination, there is a reduction in the stimulus complexity, thereby facilitating the activation of the cell assembly served by the deprived eye. This would account for the fact that the phenomenon usually occurs under darkened conditions.

The occurrence of patterns and flashing lights in the occluded eye may be due to spontaneous nervous dis-

charge following functional denervation. The difference in the time of occurrence of the two phenomena may simply be due to subject differences as only one subject reported the occurrence of both effects.

The most remarkable effect of monocular deprivation on the non-occluded eye is the fading of fixated objects, the fading being restricted to the temporal visual field. It can be suggested that such fading results from a disruption of the normal binocular competition occurring in the visual system (Guillery, 1972). There is some evidence to suggest that, in cats, monocular lid suture does not exert an equivalent effect on the layers of the lateral geniculate nucleus (LGN) (Kupfer & Palmer, 1964). Kupfer and Palmer (1964) found that laminae of the LGN receiving crossed input from the deprived eye exhibited a more rapid histological change than did those laminae receiving uncrossed afferents from the deprived eye. It is possible that those cells in the LGN receiving crossed input from the temporal field of the deprived eye cannot successfully compete with adjacent, normally innervated cells, thereby explaining why no fading occurs in the nasal field of the non-occluded eye. Those cells receiving uncrossed input from the nasal field of the occluded eye may still be capable of successful competition. Due to the asynchronous input, these cells may be capable of exerting a stronger inhibitory effect on the adjacent, normally innervated cells (serving the temporal

field of the non-occluded eye).

The absence of fading during attention may be due to the action of the reticular formation (RF) either on synaptic transmission in the LGN (Bartlett and Doty (1974) found that stimulation of the RF in monkeys altered transmission through the LGN) or in other areas of the visual system.

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APPENDIX A

SOURCE TABLES FOR ANALYSES OF VARIANCE

SOURCE	SS	df	MS	F	p
BETWEEN Ss	329.98	14	-	-	-
Conditions	30.08	2	15.04	$F < 1.00$	ns
error b	299.90	12	24.99	-	-
WITHIN Ss	301.24	90	-	-	-
Trials	30.99	6	5.17	2.97	$p < .05$
Trials x Conditions	144.98	12	12.08	6.94	$p < .01$
error w	125.27	72	1.74	-	-
TOTAL	631.22	104	-	-	-

TABLE A. Source table for analysis of variance for Experiment I.

SOURCE	SS	df	MS	F	p
BETWEEN Ss	18.68	14	-	-	-
Conditions	10.06	2	5.03	6.99	$p < .01$
error b	8.62	12	.72	-	-
WITHIN Ss	93.35	60	-	-	-
Trials	79.48	4	19.87	141.93	$p < .001$
Trials x Conditions	7.28	8	.91	6.50	$p < .001$
error w	6.59	48	.14	-	-
TOTAL	112.03	74	-	-	-

TABLE B. Source table for analysis of variance comparing MD, PC, and C groups (Experiment II) at the 0, 3, 6, 9, and 24 hour tests.

SOURCE	SS	df	MS	F	p
BETWEEN Ss	20.34	9	-	-	-
Conditions	10.02	1	10.02	7.77	$p < .05$
error b	10.32	8	1.29	-	-
WITHIN Ss	90.56	70	-	-	-
Trials	78.37	7	11.19	93.25	$p < .001$
Trials x Conditions	5.21	7	.74	6.17	$p < .001$
error w	6.98	56	.12	-	-
TOTAL	110.90	79	-	-	-

TABLE C. Source table for analysis of variance comparing MD and PC groups (Experiment II) at all test times.

SOURCE	SS	df	MS	F	p
BETWEEN Ss	.103	7	-	-	-
Conditons	.006	1	.006	F< 1.00	ns
error b	.098	6	.016	-	-
WITHIN Ss	.232	32	-	-	-
Trials	.031	4	.008	1.055	ns
Trials x Conditions	.027	4	.007	F=1.00	ns
error w	.174	24	.007	-	-
TOTAL	.335	39	-	-	-

TABLE D. Source table for analysis of variance for the non-occluded (dominant) eye of MD and PC groups in Experiment III.

SOURCE	SS	df	MS	F	p
BETWEEN Ss	.211	7	-	-	-
Conditions	.061	1	.061	2.448	ns
error b	.150	6	.025	-	-
WITHIN Ss	.202	32	-	-	-
Trials	.050	4	.013	2.119	ns
Trials x Conditions	.011	4	.003	$F < 1.00$	ns
error w	.141	24	.006	-	-
TOTAL	.413	39	-	-	-

TABLE E. Source table for analysis of variance for the occluded (non-dominant) eye of MD and PC groups in Experiment III.

SOURCE	SS	df	MS	F	p
TRIALS	28.55	5	5.71	24.83	$p<.001$
ERROR	5.43	24	.23	-	-
TOTAL	33.98	29	-	-	-

TABLE F. Source table for analysis of variance for the nine hour condition, Experiment IV.

SOURCE	SS	df	MS	F	p
BETWEEN Ss	21.64	19	-	-	-
Conditions	8.91	3	2.97	3.71	$p < .05$
error b	12.73	16	.80	-	-
WITHIN Ss	34.05	40	-	-	-
Trials	27.66	2	13.83	76.83	$p < .001$
Trials x Conditions	.79	6	.13	$F < 1.00$	ns
error w	5.60	32	.18	-	-
TOTAL	55.69	59	-	-	-

TABLE G. Source table for analysis of variance comparing groups in Experiment I and the nine hour condition in Experiment IV at 3, 6, and 9 hour test times.

SOURCE	SS	df	MS	F	p
TRIALS	25.26	5	5.052	44.91	p<.001
ERROR	2.70	24	.1125	-	-
TOTAL	27.96	29	-	-	-

TABLE H. Source table for analysis of variance for the 15 hour condition, Experiment IV.