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THE EFFECT OF SLEEP LOSS ON THE HUMAN VISUAL EVENT-RELATED POTENTIAL

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SUMMARY

Visual event-related potentials (ERPs) were obtained before, during, and after 48 hours of total sleep deprivation in fourteen volunteers. A simple flash stimulus paradigm was used to test the hypothesis that the sleep deprived brain would show changes in the amplitude and latency of the P100 component recorded from occipital regions. In addition, it was hypothesized that the recovery function of the P100 component, which is obtained by presenting paired flashes at interstimulus values from 60 to 200 milliseconds, would be altered in the sleep deprived brain relative to baseline conditions.

The results showed that the latency, but not the amplitude of P100 was increased under the condition of sleep deprivation. Furthermore, recovery functions of P100, which are represented as the ratio of the response amplitude to the first stimulus in a pair to the response amplitude to the second stimulus in a pair as a function of the interstimulus interval, did not show a demonstrable alteration as a result of sleep deprivation.

It was concluded that the visual ERP may constitute an objective means of differentiating the state of fatigue associated with sleep deprivation from normal drowsiness that occurs during the transition from waking to sleep. Whereas drowsiness is reported to be associated with increases in amplitude of ERPs, fatigue appears to be associated with increases in latency, but not of amplitude.

INTRODUCTION

One can list a large number of stimulus and organismic variables that affect the human visual event-related potential (ERP). A partial list would include characteristics of the stimulus such as intensity, pattern complexity, duration, rise time and modality; characteristics of the presentation of the stimulus such as rate, regularity, background activity and electrode location; and characteristics of the subject such as arousal level, motivation, attention, age, sex, psychopathology and presence of drugs. (For review see, for example, Perry & Childers, 1969; Regan, 1972, or Stockard, Hughes and Sharbrough, 1979).

There are also changes in ERPs during the normal transition from alertness to sleep. This intervening drowsy state has identifiable ERP characteristics. The reports of changes associated with drowsiness are consistent in indicating an increase in the amplitude of auditory ERPs relative to a baseline, but no change in latency of the major components (see, for example, Williams, et al., 1964).

The purpose of the present study was to examine the human visual ERP as a possible indicator of sleep loss effects and attendant fatigue, independent of the changes that are associated with normal drowsiness. If a distinction can be made between these two states, on the basis of ERP measurements, then a case can be made for using the ERP in monitoring fatigue associated with sleep loss. The implications of this may be of practical value. If an objective electrophysiological measure of fatigue can be developed, then the technique could be used to determine if a given individual is suffering from chronic fatigue or is merely drowsy. If the person is fatigued, the situation could be dangerous in cases involving high level performance.

In addition to the usual amplitude and latency measures, recovery functions of the ERPs were also obtained in this study. Recovery functions have been found to be sensitive to pharmacological depressants and clinical psychopathic states (Schwartz & Shagass, 1964; Bergamasco, 1966). They reported that a relative peak in the recovery function (denoted the "supernormal period") that occurs at about 100 msec may shift as a result of psychopathology (e.g. Schizophrenia) or drug treatment (e.g. Cardiozol) variables. This shift in recovery peak was obtained by stimulating the subject with pairs of identical stimuli, the pairs being separated by several different interstimulus intervals. For example, pairs of clicks might be separated by intervals ranging from 10 msec to 200 msec. The recovery function is then obtained by plotting the ratio of the first response to the second response as a function of the interstimulus interval. In effect, the recovery function is a measure of how rapidly a sensory system recovers from stimulation so that it can again show a complete response. The recovery function of the ERP obtained under the conditions of the present study was examined as a possible electrophysiological indicator of fatigue. The main hypothesis of this study was that amplitude, latency and recovery functions of the visual ERP will distinguish the sleep-deprived state from baseline conditions, and that these measures differ from that due to drowsiness per se.

METHOD

Subjects

The subjects were 14 young military enlisted men stationed at the Marine Corps and Naval Recruit Depots, San Diego, California. Each subject volunteered to stay in the lab for a seven-day period. They were told that they would be required to go without sleep for three days and two nights, and that extensive testing would take place during the days.

Experimental Procedure

After sleeping in the laboratory for two nights, ERPs and ERP recovery functions were obtained on three separate testing sessions. The first was just before the 48-hour no-sleep period (B), the second was just following the period of total sleep deprivation (TD), and the third was after one night of recovery sleep (R). The test period always occurred during the period from 1000 to 1130 hours. EEG electrodes were placed at C_z and O_2 , referenced to linked mastoids (10-20 International Electrode System). The C_z lead was used to monitor background EEG activity for drowsiness, while the O_2 lead was used for ERP measurements. Subjects sat on a hospital bed adjusted to the upright position. The front surface of a Grass PS2 Photo Stimulator was placed 25 cm forward of the glabella. A red filter was located on the surface, and a 4 mm diameter white dot was located in the middle of the red disk. Subjects were instructed to keep their eyes open and to focus on the white dot for the duration of each experimental session. The intensity of the strobe was set at 16 (approximately 19 Megalumens before the filter). A TV monitor located at the side of the bed was focused on the subject's face and provided a means of close observation of subject's face from an adjacent room. Subjects were always aroused via an intercom or by entering the room if eye closure occurred or sudden changes appeared on the EEG. A speaker located at the foot of the bed provided an auditory signal to which the subject was to respond. The visual stimulus, on the other hand, did not require a response from the subject, but was presented to him as a "warning" that preceded the auditory stimulus by 5 seconds. Upon hearing the auditory stimulus, which was randomly ordered high or low-pitch tone occurring once every ten seconds, the subject was to press the button on the right if the tone was a high pitch and the button on the left if the tone was a low pitch. Five seconds after each tone, a flash or flash-pair occurred.

All subjects had sufficient practice with the procedure prior to the first baseline day to assure that there was no confusion when the experiment began. During the test period, a total of 360 flash pairs were presented. Flash pairs were separated by 0, 60, 90, 100, 110, 120, 150 and 200 msec. There were 45 presentations per interstimulus interval (ISI) value. The 0 msec condition consisted of single flashes. Responses to the auditory stimuli were not analyzed since the tones were presented to introduce a contingency (removed in time from the visual stimulus) that would help keep the arousal and motivational state of the subject approximately constant.

Upon completing the first ERP recording session on Wednesday morning, subjects were monitored continuously for 48 hours, during which time they actively took part in a number of activities designed to prevent sleep but not fatigue them unduly. On the morning following the 48 hours of continued wakefulness and a recovery night of sleep, they again completed the test session as on the baseline day.

Data Recording and Reduction

During the ERP recording session, EEG from C_z and O_2 was recorded continuously at 10 mm/sec on a Beckman Type R Dynograph and instrumentation tape recorder. The taped EEG signal was then used to obtain ERPs from the O_2 lead on a Nicolet Model 1072 Instrument Computer and Nicolet Model SD-72/4A signal digitizer with a 4-msec filter time constant. All ERPs were pre-edited on the polygraph write-out to identify movement artifact. The resulting ERPs were based on artifact-free segments. There were 45 presentations of flashes at each ISI value. Of these, approximately 30 to 37

responses were left after editing for each ERP.

The amplitude and latency of the major positive component at 100 msec was measured, and all tests of latency, amplitude, and recovery function change were based on those measurements.

RESULTS

ERP Measurement

All subjects showed a reliable positive component at the O_2 lead for single flashes and both flashes of the flash pairs across most of the ISI values. This positive component began approximately 90 msec following the flash and reached a peak at about 100 msec. The ERPs to all 8 ISI conditions on a given session for one of the subjects is shown in Figure 1. The response to the first flash is denoted R_1 and the response to the second flash is denoted R_2 . In this example, the first 20

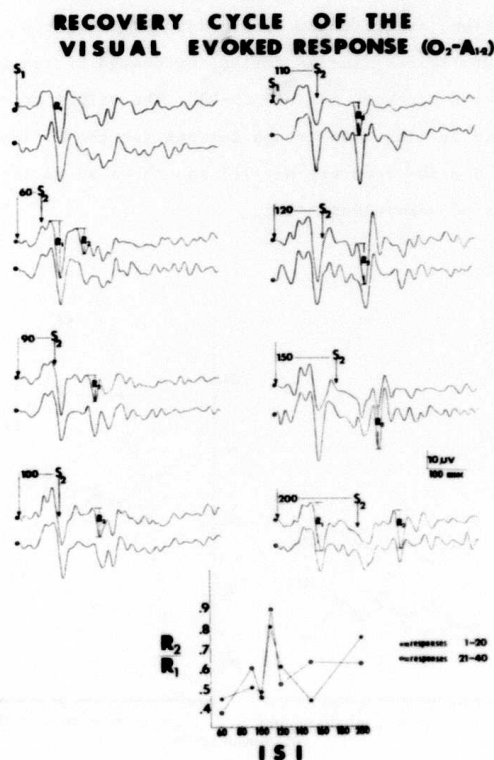


Figure 1. Visual ERPs to flash pairs and their recovery function for a typical subject. Negativity is up.

responses are compared with the second 20 responses to show reliability. The latency and amplitude of this component of the ERP was defined as follows:

Trough Latency: The number of msec from stimulus onset to the beginning of the positive component at approximately 90 msec.

Crest Latency: The number of msec from stimulus onset to the crest of the positive component at approximately 100 msec.

Amplitude: The number of microvolts at the crest relative to the beginning of the trace (at stimulus onset).

These three measurements were made on the RI and RII responses for each of the eight ISI values for each test session. The latency of RII was measured relative to the second flash in a pair. The grand means for the group are shown in Figures 2, 3, 4 and Table I. The figures are of the three measurements, trough latency, crest latency and amplitude as a function of ISI. Table I is a summary of the mean differences between days, with levels of significance given for each measurement. Each measurement was averaged across ISIs within experimental days. The differences between days is a test of the main hypothesis and is summarized in Table I. Here it can be seen that there was a significant increase in trough latency and crest latency from the baseline condition (B) to the period of 48 hrs of sleep deprivation (TD). Following the sleep period, the response is seen to return to the baseline condition, as evidenced by significant increases in these mean values in the (TD-R) comparison. This return to baseline is further evidenced by the fact that there was no difference between the Baseline and Recovery measure (B-R). The effect of sleep loss on trough latency is given in Figure 2 and Table I. The mean trough latency for the RI response is approximately 87 msec on the baseline day (B) and the recovery day (R) and shows an increase to approximately 97 msec on the day following 48 hours of wakefulness (TD).

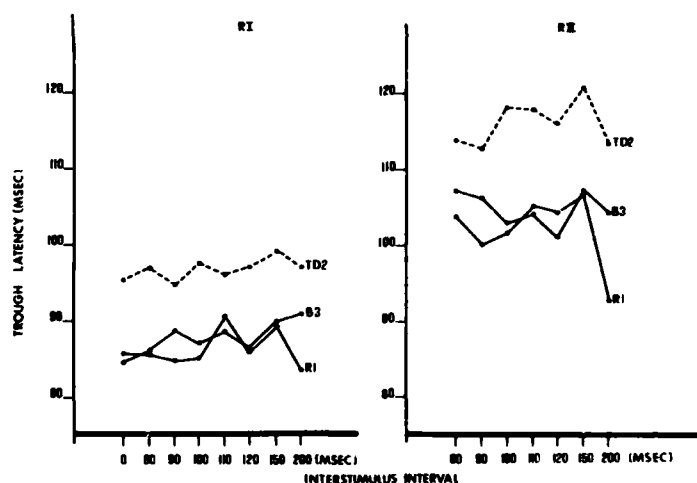


Figure 2. Trough latency of the visual ERP.

The same conclusion is reached for the mean trough latency of the RII response, but interestingly, the latencies of RII are uniformly greater. The mean trough latencies across ISIs for the RII component was 104 msec on days B and R and increased significantly to about 118 msec on day TD.

The results for crest latency are shown in Figure 3 and Table I and are similar to that for trough latency. There is a significant increase in crest latency on day TD compared to days B and R. That conclusion holds for both responses RI and RII. As was the case for trough latencies, the greatest crest latencies were observed in the RII component.

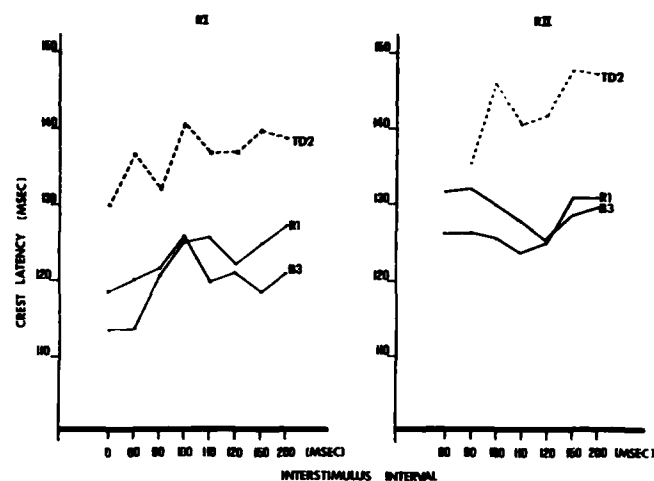


Figure 3. Crest latency of the visual ERP.

In Figure 4 and Table I are presented the amplitude of the ERP as a function of ISIs and a comparison across experimental days. In contrast to the finding for trough and crest latencies, the amplitude of this component was not significantly greater on TD than on B or R when the data were combined across ISI conditions. Individual t-tests of the amplitudes of the 0, 60, 90, 100, 110, 120, 150 and 200 ERPs ISI support the conclusion that no significant differences occur in amplitude for any of these ISIs. We conclude that amplitude of the ERP does not differentiate the sleep deprived state from the rested state. With regard to the amplitude of the ERP, a cycle of excitability can be seen in the curves for the RII response relative to the RI response. This is especially

TABLE I

Summary of ERP analysis. RI is the response to the first flash of a pair, RII is the response to the second flash of a pair. Data are mean differences in msec for the latency measures and microvolts for the amplitude measures. B = Baseline day, TD = 48 hours of total sleep deprivation, R = Recovery day after one night of sleep.

	RI			RII		
	B-TD	TD-R	B-R	B-TD	TD-R	B-R
TROUGH LATENCY	-9.07**	10.05*	.97	-12.63**	16.13*	3.49
CREST LATENCY	-16.20**	15.12**	-1.18	-13.39**	15.78**	2.40
AMPLITUDE	-1.35	1.32	-.04	.06	.29	.35

**
p < .005
*
p < .025

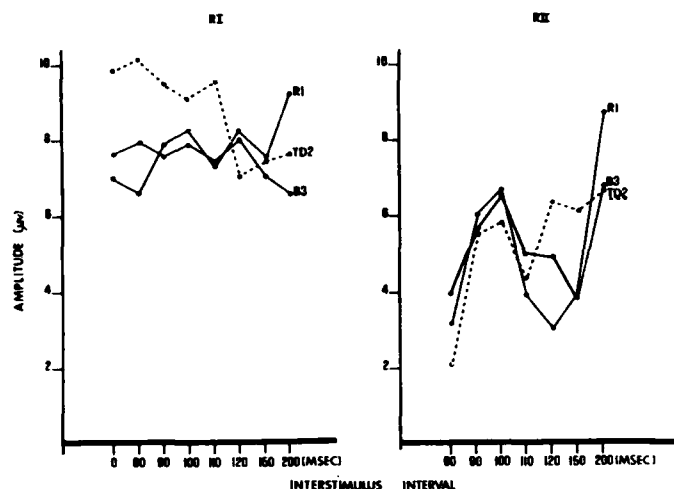


Figure 4. Amplitude of the visual ERP.

apparent on days B and R. Since these curves are very similar across days, it suggests a relatively stable phenomenon. Recovery functions were tested for a sleep deprivation effect by analysis of variance of the RII to RI ratio. This measure showed no significant difference between days for either latency or amplitude of the ERP.

DISCUSSION

In an extensive study and survey of the sources of variance of the visual ERP, Kooi and Bagchi (1964) included a variable referred to as "hours of sleep". They concluded that no relationship existed between length of sleep and amplitude and latency measurements of the ERP. In a second study, Kooi, Bagchi and Jordan (1964) systematically measured the visual ERP. During the period of drowsiness, characterized by a mixed theta and alpha background EEG, together with increased reaction times, a clear diminution in amplitude was seen, but no evidence of a change in latency. In a similar study of auditory ERPs, Williams et al. (1964) reported that the amplitude of auditory ERPs increased during drowsiness, but no changes in latency were found. In these studies the authors acknowledge that the responses evoked changed in complex ways so that waveform and the appearance and disappearance of individual components was also of importance. Nevertheless, the general conclusion seems to be that alterations in amplitude, but not of latency, characterizes the drowsy state.

In the present study, subjects had been sleep deprived for 48 hours. It was therefore natural to expect signs of drowsiness if subjects were left unattended. Every precaution was taken to insure that ERPs were obtained during periods when subjects were relatively alert and not showing signs of sleep. Given that our subjects were not being measured during drowsiness, but rather during a sleep-deprived state, we could ask the relevant question of whether that state could be distinguished from drowsiness by the visual ERP. The present evidence suggests that the distinction can be made on the basis of consideration of amplitude and latency measures. During drowsiness there appears to be a change in the amplitudes of sensory ERPs that is modality specific, but there is no apparent change in latency measures. On the other hand, the sleep-deprived brain shows an increase in latency

of visual ERPs, but no apparent effect on amplitude.

To what can we attribute this shift in latency? There may be some clues in looking at other changes of state in the brain that are associated with increased latency. Age, for one, is positively correlated with visual ERP latency, at least from adult to old age, (Vasconetto, et al., 1971). This prolongation with age may be a result of decreased nerve conduction velocity or the loss of central neurones (Brody, 1955).

Schizophrenia is also a condition that is reported to be associated with increased latency of the visual ERP (Floris, et al., 1967). Latencies of ERPs may be negatively correlated with I.Q. (Ertl and Shafer, 1973), and possibly pre-anesthetic medication or light surgical anesthesia (Domino and Corssen, 1964). A dose-dependent effect of alcohol on both background EEG and the ERP was reported by Gabbay and Lykken (1982). In that study, EEG slowing, along with a decrease in amplitude and increase in latency were observed. It thus appears that a cluster of conditions can be defined that are associated with increased latency. The sleep deprived brain is similar to each of these conditions on at least the aspect of increased latency. Contrast this with the reports that drowsiness does not affect latency, and perhaps an important distinction can be made. Drowsiness is a natural condition. It occurs when the circadian rhythms and environmental conditions are right for sleep. The sleep-deprived brain, on the other hand, is not in a normal condition. As such it may be important to identify this state and distinguish it from the state of drowsiness, a distinction that may not always be clear.

In the present study the recovery functions of ERPs did not appear to have the hypothesized differentiating effect.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → In eight volunteer subjects, the latency of both crest and trough components of visual sensory Event-Related Potentials (ERPs) was found to be increased following 48 hours of total sleep deprivation, relative to baseline levels. The amplitude of the component was not affected, nor was the recovery cycle. These results, together with previously reported data from other studies, led to the hypothesis that the ERP may be a measure of brain function →		

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20. Abstract (continued)

that differentiates fatigue and drowsiness. Whereas drowsiness is accompanied by changes in amplitude but not latency of the ERP, after sleep deprivation the opposite effect is seen; the latency of visual ERPs increases but amplitude is not affected.

The ERP may prove to be a rapidly obtained, objective measure of fatigue that does not depend on subjective responses or on complex behavioral tests.

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