

THE EFFECTS OF ATTENTION UPON THE PHOTIC DRIVING  
OF BRAIN POTENTIALS IN MAN

by  
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THE EFFECTS OF ATTENTION UPON THE PHOTIC DRIVING  
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ABSTRACT

The purpose of this investigation was to investigate the effects of varied attentive states on the electrical activity of the brain during periods of intermittent visual stimulation at high and low frequencies. The electroencephalographic (EEG) photic driving response (PDR) of seven male undergraduate college students was recorded from the occipital-parietal region under attentive and non-attentive conditions. The effect of attention on the amplitude of photic driving was recorded from mid-line occipito-parietal electrodes by means of a filter channel sharply tuned to the frequency of the flickering light.

Attention in this study was operationally defined by the task required of the S. S was required to execute a specific response to the onset and/or offset of the flickering light.

The Ss were "run" for three sessions on each of three consecutive days, eighty trials to each session. In

the non-attentive condition, the S was instructed to "observe the light." In the attentive condition, the S was instructed to "press the key as quickly as possible" contingent on the condition, i.e. to the onset, offset or to both onset and offset of the flickering light. The presentation of selected high and low frequencies, as well as the time intervals for the rest, preparatory and/ or flickering light periods were randomly varied, but the same for each condition.

The measure of photic driving was the amplitude of the wave recorded from the filter which was, as previously mentioned, triggered by the electrical activity from the mid-line occipito-parietal region. Mean driving amplitudes were compared for Ss for each of the following conditions:

- a) The first two seconds of each trial for attentive and non-attentive conditions when a response was required to the onset of the flickering light in the attentive condition.
- b) The last two seconds of each trial for attentive and non-attentive conditions when a response was required to the offset of the flickering light in the attentive condition.
- c) The intermediate period exclusive of the first and last two seconds of each trial for attentive and non-attentive conditions when a response was required to

both the onset and offset of the flickering light within the same trial under the attentive condition.

The principle results were as follows:

- 1) The amplitude of the PDR was greater for all Ss under the attentive than the non-attentive condition. This effect was more pronounced for low than high flicker frequencies.
- 2) There was a larger PDR within the attentive trials themselves when a response was required as compared to the time period in which none was required.
- 3) It was observed in the attentive condition, where, for example, an offset response was required to the flickering light, that there was an increment for the first time period as opposed to the first time period in the non-attentive condition.
- 4) A comparison of the differences in PDR between the attentive and non-attentive conditions for each of the three sessions indicated a progressive day-by-day reduction of the PDR.
- 5) A slightly greater PDR was observed for those non-attentive trials which followed a block of attentive trials. This effect was more pronounced for the non-attentive time period which corresponded to the time period which required a response in the immediately preceding block of trials. These findings are interpreted as conditioning effects.

The relation of these findings to current concepts of the neural basis of attention are discussed.

## ACKNOWLEDGEMENTS

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## BACKGROUND OF PROBLEM

Berger (1929) reported in his pioneering electroencephalographic (EEG) studies that in the waking organism, sensory stimuli will alter the electrical activity of the brain from a resting pattern of synchronous activity (8-12 cps alpha waves) to a desynchronized pattern of low voltage high frequency waves. In addition, it was found that significant changes in brain activity occurred not only as a result of sensory stimuli, but depended as well on the meaningfulness of these stimuli to the organism. Adrian (1947) found, for instance, that shifting attention from visual to auditory stimuli resulted in a resumption of alpha activity in the occipital region, i.e. the brain site for visual processes. In fact, attempting to see in a darkened room caused an arrest of occipital alpha thus being as effective as the visual stimulus itself.

Numerous observations by other workers have supported Berger's view that desynchronization of brain waves is associated with increased attention with or without the occurrence of sensory stimulation (see Lindsley, 1944). It is also known that intermittent photic stimulation can induce a state of rhythmic brain activity at the same frequency, or multiples and submultiples of the flickering light. This effect is termed the photic driving response (PDR).

This association between brain wave patterns and changing states of alertness has frequently been confirmed since the time of Berger and Adrian's original studies (Ellingson, 1956). However, the neural mechanisms remained obscure until recently. As a result of the many neurophysiological investigations over the past fifteen years, an explanation of the general processes underlying attention was suggested.

Bremer (1935), following the isolation of a cat's cortex by a mid-brain transection, observed that the animal lapsed into a somnolent state. He assumed that the somatic deafferentiation induced the somnolence and inferred that the maintenance of the waking state required the presence of somatic afferents as well as the functional integrity of the whole brain. Ranson (1939) found that if lesions in monkeys were restricted to the posterior hypothalamus near the mamillary bodies, a perpetual sleep state resulted. However, extensive bilateral lesioning of the thalamus had no disturbance on normal sleep. Nauta (1946) found similar results with rats, and in addition discovered that a lesion placed two millimeters anterior to Ranson's site of lesioning resulted in a perpetual state of wakefulness.

Moruzzi and Magoun (1949), working with anesthetized cats, discovered that electrical stimulation of the ascending reticular system (ARS) by means of implanted

electrodes resulted in behavioral arousal. The cats suddenly lifted their heads with eyes open and looked about in an apparently normal, attentive condition. Upon cessation of the stimulation, the cats immediately reverted to their former somnolent state. Activating the brain stem reticular formation (BSRF) caused a desynchronization of activity over the entire cortex. Because of its consistent association with signs of behavioral arousal, it was termed activation. Subsequent neuro-anatomical and physiological investigations disclosed that although main nerve tracts for each sensory system (designated as the main specific projection systems) projected point-to-point to their respective localized areas of the cortex, collateral fibers ramified into the BSRF. It was this second sensory system and its action through the BSRF that contributed to arousal or attention and not, as Bremer had believed, the primary sensory paths.

Lindsley, Bowden and Magoun (1949) supported these views of BSRF function by an extension of the operative procedures. Following the transection of the brain stem at progressively higher planes, increased sleep-like wave forms appeared as more and more of the reticular formation and its collaterals were severed.

Special regulatory capacities have now been assigned the BSRF. For instance, it appears to have an important influence on the transmission of impulses over

most sensory systems: in some cases preventing messages from arriving at the appropriate central receiving areas; in other cases facilitating the reception of specific stimuli, giving them temporary priority over other afferent signals. Hernandez-Peon (1956) observed that large auditory responses to a loud clicking stimulus were elicited from a resting cat which had electrodes implanted in its cochlear nucleus. However, when a bottle containing live mice was placed near the now alerted cat, the auditory responses to the constantly clicking stimulus were abolished. When the bottle was removed, however, the auditory responses to the clicking stimulus reappeared. Follow-up experiments by the same author (1956) found similar results for somatic and visual sensory pathways. The associated experiments with electrical stimulation or nembutal depression of the BSRF indicate its importance in producing these effects.

It must be stressed that this priority is not random, but seems to be related to the degree of meaningfulness of the stimulus to the individual. To illustrate the importance of signal value of stimuli, Fischgold and his collaborators (1952) found that even in conditions of stupor, the arousal value of a stimulus was not necessarily related to its intensity. In recording brain activity of a patient who was in a catatonic stupor, it was found that

neither meaningless auditory stimuli nor nociceptive stimulation such as pinching the skin altered the electrical activity of the patient's brain. However, calling out the patient's name instantly altered the activity from the typical resting pattern which consists of slow, moderately high voltage waves to one of fast, low voltage waves indicative of an alerted state.

On a more complex level, Lindsley (1958), while recording potentials from the visual cortex, observed that a single cortical response was recorded when a pair of light flashes were delivered fifty milliseconds apart. When the reticular formation was electrically stimulated for five seconds prior to the presentation of the two flashes, two separate cortical responses were recorded. Fuster (1957) found that electrical stimulation of the reticular formation in a monkey resulted in a reduction of reaction time in addition to an increment of correct responses in visual discrimination tasks as contrasted to control periods when the reticular formation was not electrically stimulated. Lansing (1959) found that visual reaction times decreased significantly when the S was alerted than when not alerted. He also observed that in the alerted state, the longer the duration of the preparatory signal, the shorter the reaction times. The reduction of reaction time paralleled the onset of alpha blocking or EEG activation. These results taken together seem to

indicate that reticular activation achieves the organization of central and cortical processes increasing efficiency of response in the visual system.

The discovery of the functional role of the BSRF gave rise to an understanding of how two separate neural systems function as an integral entity in the behavioral processes described above. It was Lorente de No (1938) who discovered that there are essentially two distinct, yet intrinsically related neural systems projecting to the cortex. These consist of the classical specific projection system and a secondary non-specific or diffuse system. A more complete resume of the structure and function of these two neural systems is well described by Jasper (1949).

The regulatory effects of the reticular formation on the special sensory systems are thought to occur through non-specific projections to cortical and sub-cortical sites. These effects have been best studied in the visual system. Two methods of measuring the visual system's response to light stimuli are evoked potentials to single flashes of light and photic driving, i.e. rhythmic potentials induced by flickering light. These may be recorded from electrodes placed at the retina, optic tract, lateral geniculate of the thalamus, optic radiations or visual cortex. Naquet et al (1959) found that reticular deactivation resulted in an enhancement of the evoked potential when recording from

the visual cortex, but no enhancement was observed when recording from the first sensory relay, i.e. the lateral geniculate body, a sub-cortical visual component. The conclusion drawn is that reticular facilitation of the visual cortex changes the excitatory state of the cortex in such a way as to enhance the cortical responses to specific stimuli. Additional literature on reticular mechanisms and evoked potentials can be found in works by Jasper (1953) and Bremer (1960). These summarize the extensive research which has demonstrated the influence of non-specific systems in modifying the responses in the specific pathways.

Photic driving, or the capacity of the brain to synchronize with a flickering light, has also been extensively employed in determining the sensory regulatory effects of reticular mechanisms. Jouvet (1958) found that attention, as defined by requiring the S to count in synchrony with a flickering light, resulted in an enhancement of the evoked potentials recorded from the visual cortex. Danilova (1961) observed that increased excitability of the cortex, as effected by increased light intensity, resulted in an increment of the PDR amplitude not only for the fundamental frequency, but also the second and third harmonics. Nineteen adult Ss were stimulated with a flickering light set at a constant flicker frequency in

the alpha range (8-12 cps) at five intensities which were repeatedly presented in an orderly sequence from low to high. The PDR of all Ss was studied under four basic conditions: sleep, sleep to wakefulness, wakefulness, wakefulness to sleep. Steriade and Demetrescu (1960) observed in "encephale isole" cats that repetitive stimulation of the reticular formation induced a driving effect in those cortical regions which had manifested no driving effect prior to reticular stimulation. The enhanced driving effect was more pronounced in the higher frequencies than the lower frequencies. Kooi and Boswell (1960) studied photically evoked cerebral patterns in man during visual, auditory and motor tasks for five frequencies: 6, 8, 10, 12, and 20 cps. The results revealed consistent alterations of the responses associated with the different tasks. For example, it was observed in nine of the ten Ss under 8 cps flicker stimulation that there was a greater PDR microvoltage from the occipital than from the motor region during a visual task while the relationship was reversed when a motor task was required. However, under 12 cps flicker stimulation, enhanced PDR microvoltage from the occipital region was observed when a motor task was required whereas a decrement in PDR microvoltage from the same region was indicated during a visual task. In short, the amount and localization of PDR is related to the task required and to flicker frequency. The frequency effects, however, were

not consistent from one individual to another.

While attempting to condition human photic driving in our laboratories, the author, acting as his own S, noted that while the time interval of photic stimulation was constant, he "felt" an increased awareness to the offset of the photic stimulator. Varying the time interval of photic stimulation in addition to executing a response (tapping at the offset of the flickering light) resulted in a greater PDR increase during the last few seconds of photic stimulation than for a similar control period when no response was required. A preliminary study using one S under similar experimental conditions to those for this project, likewise showed a greater PDR under attentive than non-attentive conditions. On the basis of these preliminary results and the extensive experimental literature cited above, it seemed reasonable to extend the investigation of the effects of attention on the PDR in man.

In the present study, an attempt was made to maximize the effects of attention by giving meaning to the flickering light itself. This was accomplished by requiring the S to respond rapidly to the onset or offset of the flickering light under the attentive condition, and to simply observe the light under the control or non-attentive condition. It was predicted that photic driving amplitude would be greater when the S is required to react to the

onset or offset of the flickering light than when not required to respond. It was further predicted that PDR would progressively build up near the end of a flicker burst when the subject was required to respond to its offset because this is the period in which attention would undoubtedly be expected to increase. Likewise, it was expected that PDR would decrease following the onset of the flickering light to which the S had just responded since attention would ordinarily decrease. In addition to this, the effects of low and high flicker frequencies under attentive and non-attentive conditions were studied.

## METHOD

Seven male undergraduate college students were used as subjects. Disk electrodes were placed on six positions of the scalp to record the electrical activity from the occipital-parietal region: the mid-line occipital, mid-line parietal, right occipital, right parietal, left occipital and left parietal. A plastic template was employed with the inion as point of reference to insure consistent electrode placement for each test session. The EEG data were recorded on a six channel Grass Model 5 Polygraph with 5P5 EEG preamplifiers. A typical recording is shown in Figure 1.

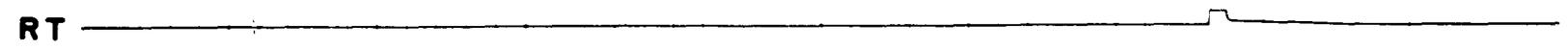
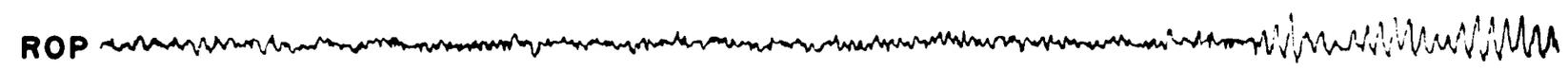
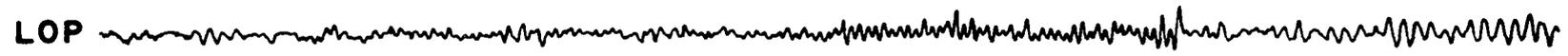
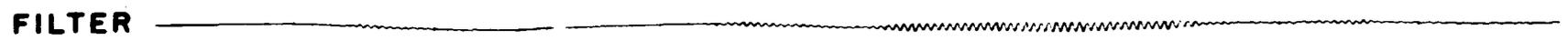
Brain activity from the mid-line occipital-parietal, left occipital-parietal and right occipital-parietal regions were recorded on channels 1, 4 and 5 respectively. Channel 2 recorded mid-line occipital-parietal activity with a sharply tuned filter ( $Q = 1.6$ ) which, prior to each trial, was adjusted to respond only to that frequency which was coincident with the flickering light. The flickering light stimuli were monitored on channel 3 which recorded the responses of a photo cell positioned near the photic stimulator. Channel 6 recorded the Ss reaction time responses.

The Ss were seated in a ventilated, sound deadened, electrically shielded room illuminated by a dim overhead lamp. A telegraphy key was affixed to the arm rest of the

Figure 1

EEG recording at 18 cps for six second burst  
of photic stimulation requiring offset response.  
(Note the PDR enhancement during the last two  
seconds of flicker burst.)

485



1 SEC.

Ss chair. The photo stimulator, a Grass PS-2 stroboscopic lamp measuring five inches in diameter and standardized at intensity four, was placed in front of the S approximately five inches from his nasion. This distance was held constant by an adjustable bar with a head rest attached at one end and the lamp at the other. Attached to the underside of the bar was a short tubular device containing a small bulb which projected a pin-point of illumination on a central fixation point marked upon the opal glass front of the lamp. This device served as a ready signal in the attentive phase of the experiment to be described below.

The Ss EEG responses to a flickering light were studied under attentive and non-attentive conditions. The condition of attentiveness was defined operationally in this study by requiring the S to execute a specific response to the onset and/or offset of a flickering light. No response was required of the S in the non-attentive condition.

A preliminary test was conducted in which each subject was briefly exposed to the flickering light at frequencies ranging from four to twenty cycles per second (4-20 cps) to determine the S's percent time driving, i.e. the percentage of photic driving in a given time interval of photic stimulation. The Ss selected were those whose percent time driving was between thirty and eighty percent for each of the sixteen preliminary test frequencies. Two frequencies, one in the low range (4-6 cps) and the other

in the high range (16-20 cps), were then selected for each S. The particular frequencies selected were those for which the S demonstrated the best photic driving. The frequency range of 8-12 cps was avoided so as to remove any doubt that what might be interpreted as photic driving was simply an enhancement of the S's alpha or spontaneous rhythm.

The photic driving response (PDR) of each S was studied under attentive (A) and non-attentive (NA) conditions, at high and low flicker frequencies, according to the following design:

<u>Session 1</u>	<u>Session 2</u>	<u>Session 3</u>
NA (10)	NA (10)	NA (10)
A-onset (20)	A-offset (20)	A-onset & offset (20)
A-offset (20)	A-onset & offset (20)	A-onset (20)
A-onset & offset (20)	A-onset (20)	A-offset (20)
NA (10)	NA (10)	NA (10)

The three sessions described in this design were held on each of three consecutive days. The order of the three attentive conditions: response to the onset of the flickering light, response to the offset of the flickering light or responses to both the onset and offset of the flickering light within the same trial, was varied from session to session. The selected high and low frequencies were randomly varied

for each and every trial under both attentive and non-attentive conditions. The number of trials for each experimental condition is shown in parentheses.

The experimental components of each trial for both the attentive and non-attentive conditions were as follows:

NA	_____....._____	<u>Key</u>
A-onset	_____----*....._____	_____ Rest period
A-offset	_____.....*_____	---- Ready light
A-onset & offset	_____----*.....*_____	.... Flickering light
		* Reaction time response

Under the non-attentive condition, the Ss were instructed to "observe the flickering light." Under the attentive conditions, the Ss were instructed to "press the key as rapidly as possible" to the onset, the offset or to both the onset and offset of the flickering light. The Ss were also informed that, prior to each trial requiring an onset response, a pin-point of light would be cast upon the glass pane of the stimulator to serve as a preparatory signal indicating that it, the photic stimulator, would commence flashing within a few seconds.

The time intervals for the rest, preparatory and/or flickering light periods for both attentive and non-attentive conditions were predetermined and randomly varied

for each and every trial. The time periods were controlled by three Hunter Model 111-C silent timers with the time limits for any one trial component ranging from four to ten seconds. The purpose of varying the duration of each trial component was to avoid the possibility of habituation which could result in a conditioning effect negating the original purpose of this experiment. A brief rest period (5-10 mins.) was given between each block of trials irrespective of condition.

The Ss PDR under the non-attentive condition in which minimal attention was given to the flickering light was compared to the PDR under the attentive condition where maximal attention and meaningfulness were given to the flickering light. The measure of PDR in the present study was amplitude of the photic driven wave from the mid-line occipital-parietal region as indicated by the filter channel which was tuned to the frequency of the flickering light. The filter response amplitude of each wave for each S under attentive and non-attentive conditions were measured to the nearest millimeter for the time periods indicated below:

- a) The first two seconds of each trial under attentive and non-attentive conditions when a response was required to the onset of the flickering light in the attentive condition.

- b) The last two seconds of each trial under attentive and non-attentive conditions when a response was required to the offset of the flickering light in the attentive condition.
- c) The intermediate period, exclusive of the first and last two seconds of each trial, under attentive and non-attentive conditions when a response was required to both the onset and the offset of the flickering light under the attentive condition.

Since the components of a single trial in this study, for both the experimental conditions mentioned above, are characterized by the first two seconds, the last two seconds and an intermediate interval which is variable, they will be designated as the first, last and intermediate time periods respectively.

## RESULTS

A greater amplitude of PDR was found for all Ss under the attentive than under the non-attentive conditions. This was true for both high and low frequencies, but the effects of attention were more pronounced for the low frequency. A summary of this data is found in Table 1, which indicates the mean PDR amplitude for the high and low frequency conditions, and for the first and last time periods. The significance of the effects of these conditions on photic driving amplitude was tested with the Wilcoxon Matched-Pairs Signed-Ranks Test for Paired Replicates (one-tailed). This testing was based on a comparison of the mean PDR amplitude for each individual under the experimental conditions being studied. The direction and magnitude of these difference scores, replicated for seven Ss, are taken into account by the Wilcoxon Test in determining if the experimental effects could have occurred by chance. The differences in PDR between attentive and non-attentive conditions, comparing the same time periods, and the greater attentive effect under low frequency than high frequency conditions, were statistically significant ( $P < .01$ ).

Figures 2 and 3 show the amplitude of PDR for each S individually. The main effects summarized above for the

MEAN WAVE AMPLITUDE (IN MILLIMETERS) FOR ALL Ss  
 COMBINED FOR FIRST AND LAST TIME PERIODS  
 UNDER ATTENTIVE AND NON-ATTENTIVE  
 CONDITIONS FOR BOTH HIGH  
 AND LOW FREQUENCIES

Time Periods	High Frequency		Low Frequency	
	Attentive	Non- Attentive	Attentive	Non- Attentive
First	.506	.293	1.429	.851
Last	.504	.276	1.567	.868
Total Mean	.505	.284	1.498	.859

**Figure 2**

The mean wave amplitude (in millimeters) for each S for the first and last time periods combined under attentive and non-attentive conditions at low frequency.

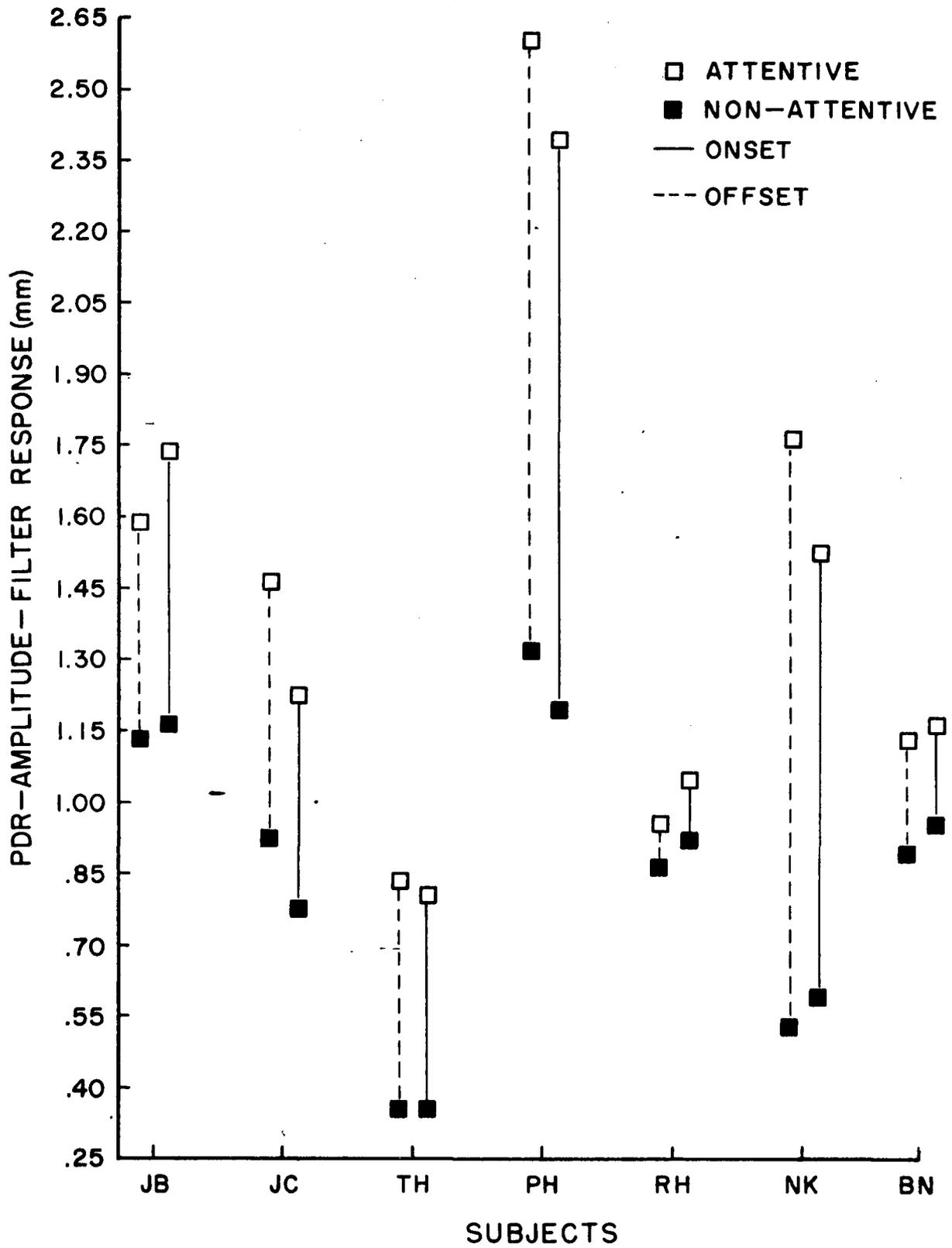
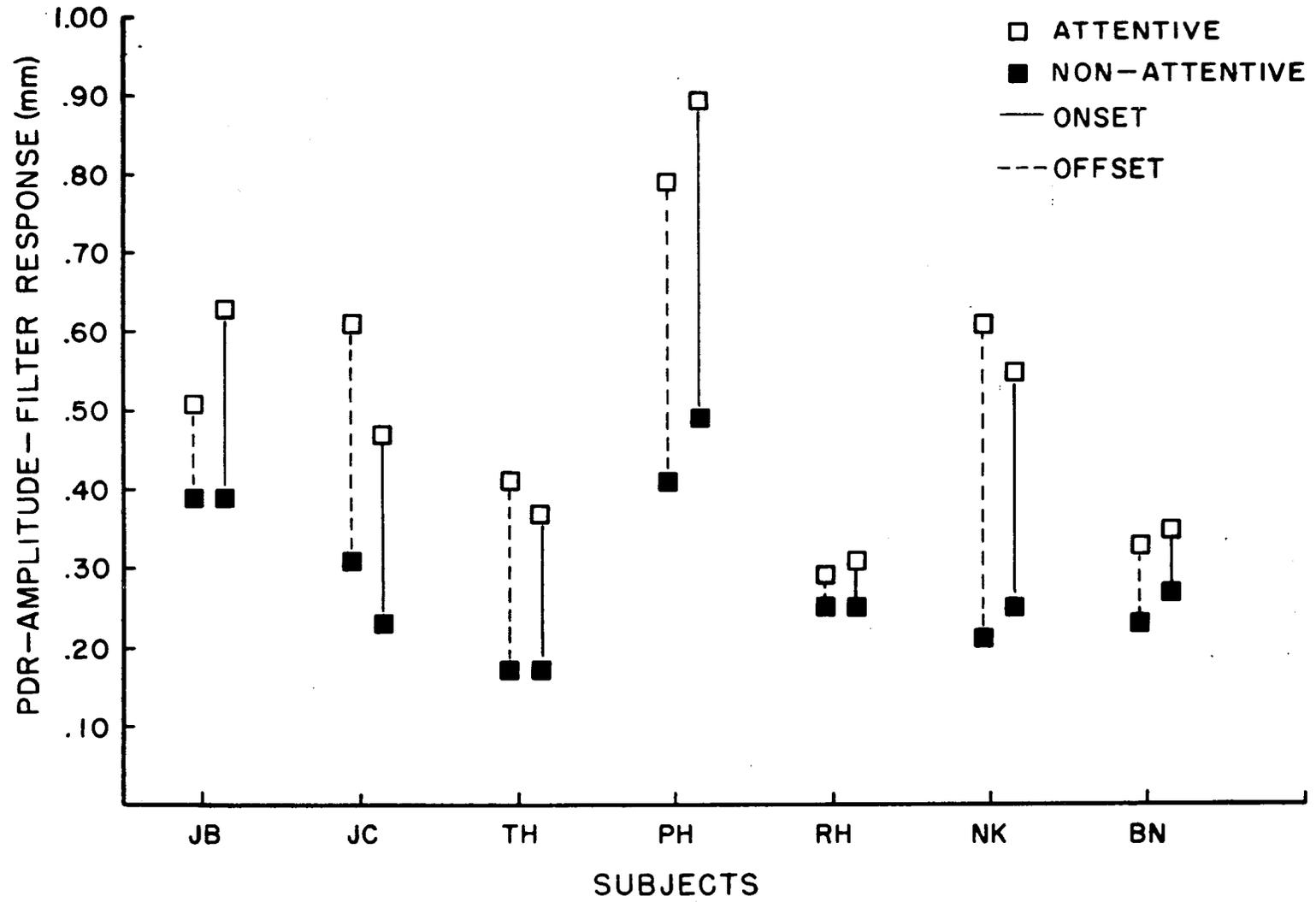


Figure 3

The mean wave amplitude (in millimeters) for each S for the first and last time periods combined under attentive and non-attentive conditions at high frequency.



group are here seen to be clearly present for each S. Although the direction of the change is the same for all Ss, considerable variability is noted from S to S in the amount of PDR increase under attentive as compared to non-attentive conditions. Figure 2 illustrates these effects for low flash rates and Figure 3 for high flash rates.

Within the attentive trials themselves, comparisons were made of the PDR for the time periods when a response was required and those in which no response was required. For instance, in the offset attentive condition, a response is required at the cessation of the flickering light rather than its onset. The first time period may then serve as a "non-attentive" control period against which to compare the effects of attention operating in the last time period when the offset response is required. Similarly, the last time period may serve as a "non-attentive" control during the onset conditions during which a response is required at the onset, but not offset of the flickering light trial. All such comparisons made within the attentive condition trials themselves were found to be significant ( $P < .01$  with a one-tailed Wilcoxon Test).

These intra-attentive condition effects are more clearly seen in Figures 4 and 5. The mean wave amplitude of PDR is presented for all Ss combined for each second of

Figure 4

The total mean wave amplitude (in millimeters) for all Ss combined for each second of all the eight second, low frequency trials, under attentive and non-attentive conditions for the first session.

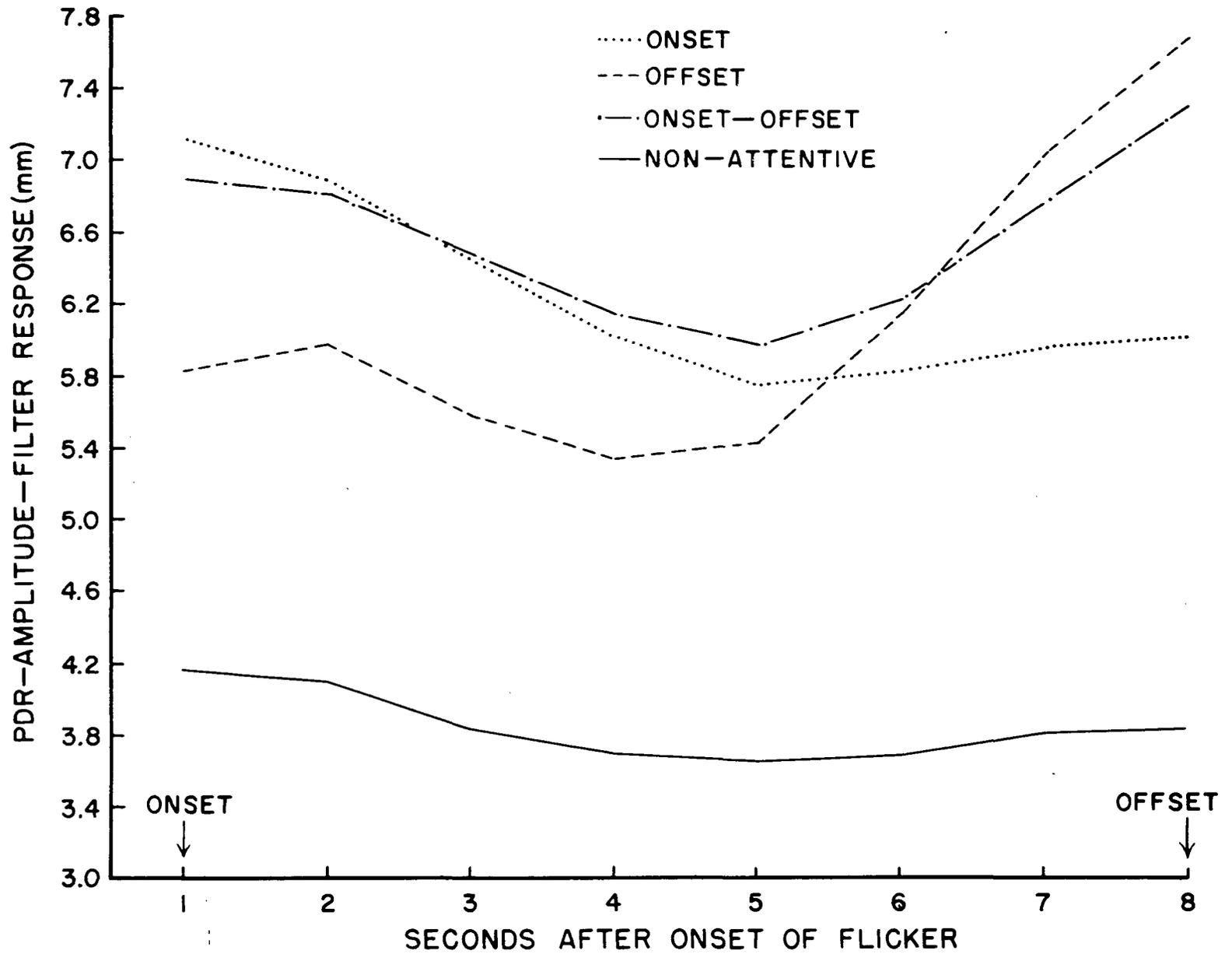
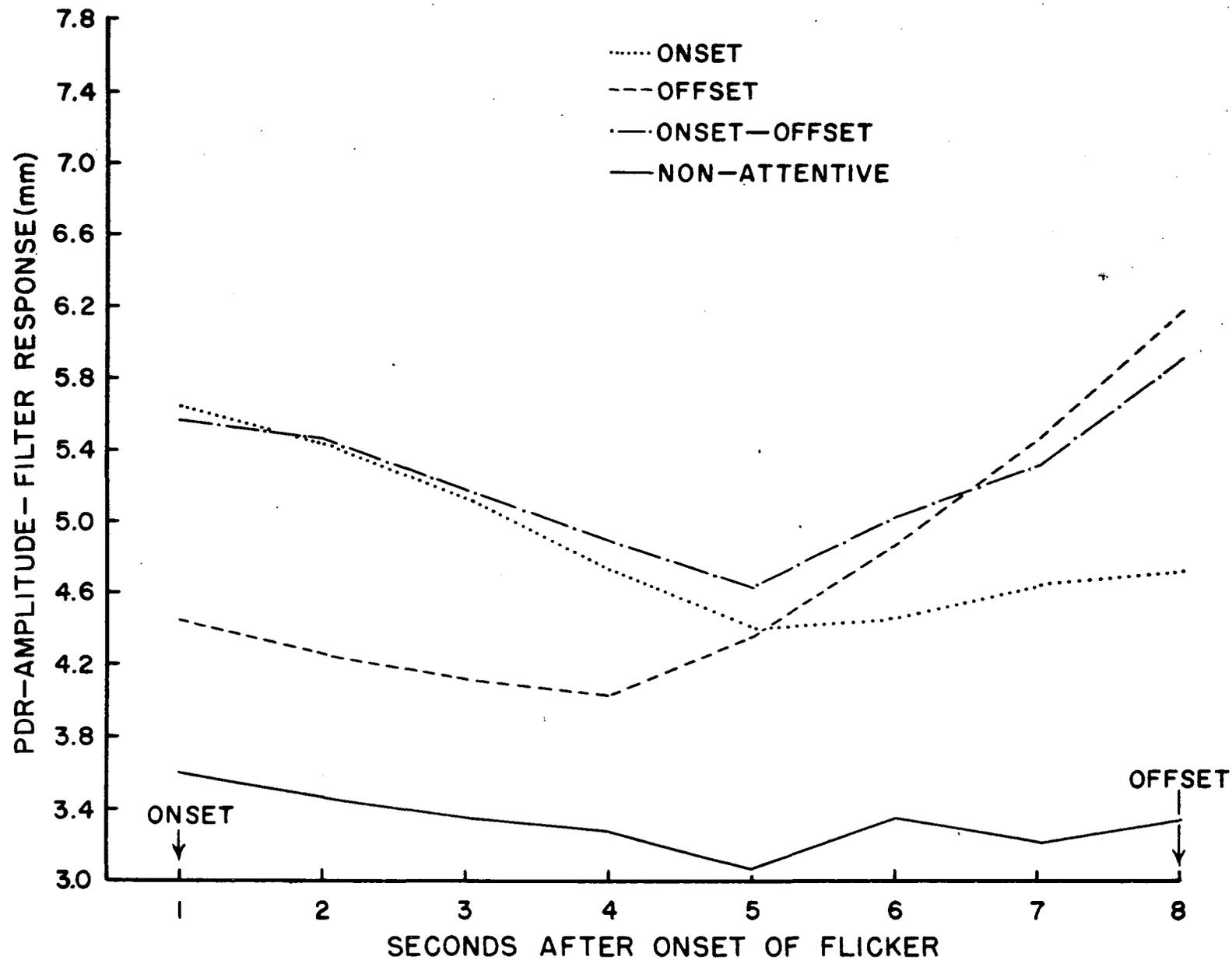


Figure 5

The total mean wave amplitude (in millimeters) for all Ss combined for each second of all the eight second, low frequency trials, under attentive and non-attentive conditions for the last session.



all the eight second, low frequency trials. Figure 4 shows the plotting of this data for the first session, and Figure 5 for the last session. Values are given for both non-attentive and attentive conditions. Note that in both figures when only an onset response is required, there was a larger PDR for the first time period than the last time period. There was also a greater PDR for the first time period of the offset trials. When an offset response was required, the PDR was larger for the last time period than for the first time period. There was also greater PDR in the last time period for the offset trials than the last time period for the onset trials. Inspection of these figures shows that, as predicted, the increase and decrease of photic driving amplitude follows the same time course expected for the increase and decrease of attention; decreasing following the onset response, increasing preparatory to the offset response.

It is of considerable interest that when S was required to execute a response to the offset of the flickering light, there was a larger PDR for the first time period than the first time period in the non-attentive condition. Figures 4 and 5 also illustrate this effect very clearly for all time periods. This demonstrates an increase of photic driving amplitude under the attentive condition even during the time periods in which no response is required.

These were likewise significant at the  $P < .01$  for a one-tailed test (Wilcoxon).

There appeared to be a progressive day-by-day reduction of the PDR for both high and low frequencies under both attentive and non-attentive conditions. However, this order effect over sessions was not statistically significant. This was true both for the day-to-day comparison of absolute scores and for the day-to-day comparison of difference scores between the attentive and non-attentive conditions. In other words, despite an apparent consistent decrement in PDR for all Ss from the first to the second, the first to the third, and the second to the third sessions, the reduction was not statistically significant (employing both the Friedman Two-Way Analysis of Variance and the Wilcoxon Test).

Further analysis of the PDR for each S in the non-attentive condition alone demonstrated a significantly greater PDR for those non-attentive trials which followed a block of attentive trials than for those occurring at the first of a session before the attentive trials were given. This effect was clearly seen for the non-attentive time period which corresponded to the time period which required a response in the immediately preceding block of trials in the attentive condition. For example, if the block of attentive trials, immediately preceding the

non-attentive trials, required a response to the onset of the flickering light, the first time period for the non-attentive trials showed greater driving than the same time period of the non-attentive trials given at the first of the session. These findings could be broadly interpreted as conditioning effects.

## DISCUSSION

The results of this study support the hypothesis that attention facilitates photic driving activity. This is in general agreement with the results obtained by Danilova (1961) and Steriade and Demetrescu (1960). The results are also in agreement with those reported by Kooi and Boswell (1960) who found that, in man, the PDR to a flickering light was enhanced in the occipital region during a visual task. However, there was a decrease in PDR when the task was shifted from visual to motor in nature. It was assumed that PDR enhancement in the visual cortex during the visual task would occur since the flickering light was more meaningful. Thus, in the present study, the results could be explained on the same basis since the PDR was enhanced under the attentive condition in which the flickering had more signal value. This would indirectly support Gastaut's (1951) that SS whose resting record exhibited a fast, low voltage pattern corresponding somewhat to an activation pattern, should have a greater PDR than those whose resting record is of moderately fast, high voltage activity.

The mechanisms which could account for this enhancement on the basis of past research would point to the reticular formation together with the non-specific projection system since they are related to and interact with

the activities of the classical specific projection system. As previously stated, Steriade and Demetrescu observed that PDR could be elicited from the visual cortex of a cat by a flickering light which had no "driving" effect prior to the stimulation of the reticular formation. Lindsley (1957) recorded two evoked potentials corresponding to two light flashes 73 milliseconds apart following five seconds of reticular stimulation whereas without reticular stimulation, only a single potential was recorded under the same conditions. Jung (1957) found that reticular stimulation increased the S's critical fusion frequency (cff) to a flickering light by 10-15 cps. Upon cessation of reticular stimulation, however, the visual cortex was unable to respond to the repetitive flicker stimulation induced by reticular stimulation.

The question of where in the visual system the enhancement specifically occurs is not too clear. Granit (1955) recorded increased "firing" of retinal units by stimulating the reticular formation. Steriade and Demetrescu, recording from the optic tract and visual cortex, prior to reticular stimulation, observed a normal response of the optic tract to follow the light flicker, but the response at the visual cortex was markedly reduced if not absent. However, with reticular stimulation, while no change in the response from the optic tract was observed, the records revealed a rhythmic

response from the visual cortex identical with the flicker frequency.

At the level of the lateral geniculate body (first sensory relay of the visual system) Steriade and Demetrescu observed enhanced responses from this visual component to fast flicker frequencies when the reticular formation alone, or together with the cerebellum, was stimulated. These authors thus contend that enhancement at the geniculate and cortical levels are not the result of retinal facilitation since no significant changes occurred at the level of the optic tract. Hernandez-Peon (1956) corroborated Granit's results, but found that reticular stimulation depressed photic potentials recorded from the lateral geniculate body in addition to either a potentiation or depression of the optic tract potentials which contradicts, in large measure, the results obtained by Steriade and Demetrescu. Dumont and Dell (1958) observed that responses from the visual cortex, evoked by stimulating the visual afferent pathways (optic tract, lateral geniculate body and optic radiations), were enhanced by reticular stimulation.

At the cortical level, Purpura (1957) argues that inhibition and excitatory post-synaptic potentials are the critical elements determining inhibition and facilitation in the cortical dendritic fields. It is conceivable that reticular non-specific influences might act at a cortical

level directly through axodendritic influences on the apical dendrites or through some intermediating neurons which may then influence the dendritic fields through excitatory or inhibitory mechanisms. Increased photic driving activity, according to this conception, may result either by reducing the inhibitory or increasing the excitatory state of the dendritic field.

The question of enhanced photic driving activity as a function of frequency is not clearly demonstrated. In the present study, the data indicate greater enhancement in the lower frequencies (4-6 cps) whereas Steriade and Demetrescu found greater enhancement in the higher frequencies (7-20 cps). Lansing (unpublished data) measured PDR in thyroid patients diagnosed as hypothyroid at the time of first EEG recording session. Following six weeks of thyroid hormone replacement, increasing their alertness, Lansing again measured the patients' PDR and observed an overall enhancement, but it was greater for the higher frequencies. It must be stressed, however, that many of the studies such as those mentioned above involve animal Ss who, in some way, have had their brain structure altered. In the case of Lansing's study also, the Ss, adult men and women, had a past history of a pathological thyroid condition which may have altered, to some degree, the neural mechanisms which are responsible for the

phenomenon in question.

There are several questions which, according to this author, require further investigation as a result of this study. They might include:

- 1) An attempt to determine if, as reported by Kooi and Boswell, the reversal of PDR enhancement from the visual to motor cortices is actually a function of increased flicker frequencies or, as this author believes, a function of intensity which increases as a result of higher flicker frequencies.
- 2) An attempt to condition photic driving in man, as suggested in the present study, when comparing the first time periods for the offset trials under the attentive condition for the first and last sessions as seen in Figures 4 and 5. Morrell (1957) presented evidence that photic driving activity could be conditioned in cats.
- 3) An attempt to determine the physiological limits of PDR. In other words, while maintaining similar experimental conditions as in the present study, would increasing the difficulty of discriminating, i.e. a disjunctive rather than a simple reaction time response, enhance PDR still more and/or cause a shift of PDR from one cortical region to another?

## SUMMARY

The photic driving response (PDR) of seven college students was obtained for both high and low frequencies under attentive and non-attentive conditions. Attention was operationally defined by the task required of the S. The Ss were required to execute a specific response to the onset and/or offset of a flickering light under the attentive condition while none was required in the non-attentive condition. Three sessions were held on each of three consecutive days, eighty trials for each session. The measure of the PDR was amplitude of the wave recorded from a filter which was sharply tuned to the frequency of the flickering light, and triggered by the electrical activity from the mid-line occipito-parietal region. The mean driving amplitudes were compared for Ss for each of the following conditions:

- a) The first time period of each trial for attentive and non-attentive conditions when a response was required to the onset of the flickering light in the attentive condition.
- b) The last time period of each trial for attentive and non-attentive conditions when a response was required to the offset of the flickering light in the attentive condition.

- c) The intermediate time period exclusive of the first and last time periods of each trial for attentive and non-attentive conditions when a response was required to both onset and offset of the flickering light within the same trial under the attentive condition.

The principal results of this investigation were:

- 1) PDR amplitude was greater for all Ss under attentive than non-attentive conditions. This enhancement was more pronounced for the low than high frequencies.
- 2) There was a larger PDR within the attentive trials themselves when a response was required as compared to the time period in which none was required.
- 3) It was observed in the attentive condition, where, for example, an offset response was required to the flickering light, that there was a PDR increment for the first time period as opposed to the first time period in the non-attentive condition.
- 4) A comparison of the differences in PDR between attentive and non-attentive conditions for each of the three sessions indicated a progressive day-by-day reduction of the PDR.
- 5) A slightly greater PDR was observed for those non-attentive trials which followed a block of attentive trials. This effect was more pronounced for the non-attentive time period which corresponded to the time

period which required a response in the immediately preceding block of trials. These findings were interpreted as conditioning effects.

The first three results mentioned above were found to be significant at the  $P < .01$  level for a one-tailed test (Wilcoxon), and supports the main hypothesis that the PDR would be greater under attentive than non-attentive conditions.

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