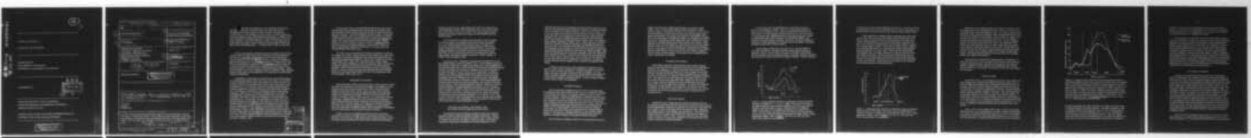
AD-A050 041 CALIFORNIA UNIV LOS ANGELES DEPT OF PSYCHOLOGY F/G 5/10
ACTIVATION AND ATTENTION.(U)
DEC 77 J BEATTY N00014-76-C-0616
UNCLASSIFIED TR-13 NL

| OF |

AD
A050041



END
DATE
FILMED
3 -78
DDC

(12)

TECHNICAL REPORT #13

ACTIVATION AND ATTENTION

JACKSON BEATTY
DEPARTMENT OF PSYCHOLOGY
UNIVERSITY OF CALIFORNIA AT LOS ANGELES

1 DECEMBER 1977

PREPARED FOR OFFICE OF NAVAL RESEARCH
PHYSIOLOGY PROGRAM, ENVIRONMENTAL PHYSIOLOGY
CONTRACT N00014-76-C-0616

REPRODUCTION IN WHOLE OR IN PART IS PERMITTED FOR ANY PURPOSE OF THE UNITED STATES GOVERNMENT

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
13

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) Activation and attention.

5. TYPE OF REPORT & PERIOD COVERED
(9) Interim Technical Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) Jackson Beatty

8. CONTRACT OR GRANT NUMBER(s)
(15) N00014-76-C-0616

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Psychology
University of California, Los Angeles
Los Angeles, California 90024

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
NR 201 - 207

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of Naval Research (Code 441)
Department of the Navy
Arlington, Virginia 22217

12. REPORT DATE
(11) 1 December 1977

13. NUMBER OF PAGES
17

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(12) 19p. (14) TR-13

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Distribution unlimited

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

16. SUPPLEMENTARY NOTES
Published in M. C. Wittrock, J. Beatty, J. E. Bogen, M. S. Gazzaniga, H. J. Jerison, S. D. Krashen, R. D. Nebes, & T. Teyler, The human brain. Englewood Cliffs, New Jersey: Prentice-Hall, 1977.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Activation
Attention
Pupillometry

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

A series of experiments using pupillometric and electroencephalographic measures are reviewed. In each experiment, a close relation is observed between the psychological processes of attention and the physiological indications of increased phasic activation. From these data, the rudiments of an activation theory of attention are proposed. This study was also → published in 'The Human Brain', by M. C. → Wittrock, et al., 1977.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102 LF 014 6601

072 268 LB

"E[illegible] one knows what attention is. It is the taking possession by the mind, [illegible] clear and vivid form of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others... Fatigue, monotonous mechanical occupations that end by being automatically carried on, tend to produce a state of non-attention in men. It is not sleep; and yet when aroused from such a state, a person will often hardly be able to say what he has been thinking about.... (William James, 1890, pp. 403-405).

At least three separate meanings for the term attention may be found in these words of William James, the celebrated American psychologist who wrote his *Principles of Psychology* at the end of the 19th century. James' attention is at once a *selective* process--in which some things are perceived and others are not, an *intensive* process--in which more or less effort or concentration is employed, and a *sustaining* process--which acts to maintain the general capacity of the organism to process information during monotonous, repetitive tasks in unstimulating environments. These three meanings in fact refer to different aspects of attention, which, although related to each other and interdependent, are nonetheless at least partially distinct and separable.

Unfortunately, the problem of attention in its various aspects faded from American psychology in the early years of this century and remained virtually unstudied until the 1950s. The reasons for this are several, but primarily reflect the widespread belief in those years that behavior could be understood as a set of more or less fixed relations between stimulus events and responses, with little regard for active intervening processes. The re-emergence of attention as a compelling problem for psychology developed, in large part, in response to advances made in the areas of neurophysiology, neuroanatomy, neuropsychology and physiological psychology, that began to reveal the complexity of brain processes that mediate behavior. In particular, the physiological and behavioral work that followed Moruzzi and Magoun's (1949) discovery of the reticular activating system's role in regulating brain activation played an important role in reawakening scientific interest in the problem of attention. Subsequent work has led to a new conception of the relations between cortex and brainstem. Higher cortical information processing functions began to be seen as dependent upon the integrative, activating processes of the brain stem core. This view suggested that the behavioral phenomena of attention in its various aspects might be related to the physiological processes of activation (Lindsley, 1960).

In the present chapter, two experimental approaches to the study of attention that we have employed in our laboratories are presented. Both are concerned with the relations between measures of brain activation and behavioral attention. The first investigates peripheral signs of momentary changes in activation that occur during cognitive processing in an attempt to understand the empirical relations between activation and intensive attention. The second explores the relationship between longer lasting changes in cortical activation as they are related to sustained attention and performance in prolonged monotonous vigilance tasks. These two lines of experimental research are illustrative of current work on the neuropsychology of attention in man.

The reader who is interested in the problem of attention is referred to a number of excellent reviews which have been published in recent years. The problem of selective attention has been extensively treated with both behavioral and physiological methods. This work is summarized in reviews by Broadbent (1970), Egeth (1967), Kahneman (1973), Moray (1969a, 1969b), Swets and Kristofferson (1970), and Treisman (1969). The question of intensive attention has been less fully explored, but recent books by Kahneman (1973) and Norman (1976) review much of what is now known in this area. Several volumes have also been published that treat sustained attention in considerable detail (Davies & Tune, 1969; Mackworth, 1969, 1970; Mostofsky, 1970; Stroh, 1971).

MEASURING ACTIVATION

Several different methods may be employed to measure nervous system activation, each having its own particular strengths and weaknesses. Measuring cortical brain rhythms is one obvious choice, since these waves originate in the cortex itself. Further, there are well-known relations between EEG patterns and activation; desynchronization of ongoing brain rhythms may be taken as an indication of cortical activation with a fair amount of certainty (Lindsley, 1960). However, with conventional analysis procedures, a considerable period of EEG activity must be analyzed to yield a stable estimate of cortical synchrony or desynchrony (Kellaway & Petersen, 1973). For this reason, EEG measures of synchrony and desynchrony are more useful as indicators of activation over long periods of time, as in the study of sustained attention, than as indicators of momentary activation shifts required in the study of intensive attention.

Another class of EEG analysis procedures involves measuring small electrical events occurring in cortex immediately following the presenatation of brief stimuli. These event-related cortical potentials, as they are called, have been studied in a wide variety of information processing situations and the results of such experiments have been extensively reviewed elsewhere (Karlin, 1970; McCallum & Knott, 1973; Picton & Hillyard, 1974; Posner, 1975; Tecce, 1970, 1972). Event-related cortical potentials have proven useful in the analysis of both intensive and sustained attention.

A third procedure for studying the rapid shifts in nervous system activation in cognitive processing is based upon the fact that changes in nervous system activation are present not only in the activity of the cortex, but also appear in the peripheral portions of the nervous system, particularly in the autonomic nervous system. Of the various peripheral indicators of autonomic activation, the movements of the pupil of the eye are perhaps best suited for investigating the relationships between activation and thought (Kahneman, Tursky, Shapiro, & Crider, 1969; Loewenfeld, 1958).

As early as 1920, Lowenstein recognized that the pupil of the eye dilates during cognitive activity (Goldwater, 1972). These dilations may be observed under conditions of constant illumination and are quite independent of the well-known light reflex, which constricts the pupil as illumination increases. Pupillary movements are produced by changes in the relative activation of two muscle groups in the iris. One set of iris musculature, the dilator pupillae, are radially oriented smooth muscle fibers that are innervated by fibers from the sympathetic branch of the autonomic nervous system. Sympathetic activation, therefore, acts to dilate the pupils. Functionally and structurally opposed to the dilator pupillae are the parasympathetically-innervated muscles called the sphincter pupillae, which constrict the pupil as they contract. Thus momentary pupillary diameter reflects the activation of both sympathetic and parasympathetic musculature. In terms of gross autonomic function, pupillary dilation may be interpreted as a sign of autonomic activation. However, it is only in the last few decades that the systematic nature of the relations between autonomic activation and cognitive processing have become apparent (Goldwater, 1972; Janisse, 1974). They provide a method by which to undertake the study of activation and the higher cognitive processes of the human brain, since the peripheral signs of autonomic activation are readily measurable in man.

INTENSIVE ATTENTION, PROCESSING LOAD, AND TASK-INDUCED CHANGES IN ACTIVATION

The activation theory of intensive attention proposes that cognitive processes require specifiable amounts of intensive attention or "mental effort" for their execution and that the momentary level of effort involved is reflected in momentary increases in brain activation, which may be measured by appropriate physiological techniques (Kahneman, 1973).

The theory predicts that the activation increases should be larger for more difficult processing functions and should be related in a systematic fashion to the momentary level of effort required to perform those functions. The idea is that cognitive functions can be characterized by their information processing load, or the demands for capacity that they impose upon the organism, and that processing load can be measured by the momentary level of task-induced activation (Kahneman & Beatty, 1966). We proposed a simple analogy (Kahneman & Beatty, 1967) to clarify this idea: In a home filled with a variety of electrical appliances, the aggregated demand for electrical power rises and falls as the appliances are switched on and off. The momentary level of demand for power could be measured using the appropriate instrument attached to the electrical line outside the house. Information processing load was conceived as analogous to the total demand for power required to perform a particular set of information processing functions at a particular moment in time. Notice that this concept depends not so much upon what stimuli are presented to the organism, but upon the internal processes that the organism uses to handle environmental information.

Autonomic activation may, under appropriately specified circumstances, reflect cortical demands for momentary activation by the brainstem to permit cortical processing of complex information. For this reason, the study of pupillary movements during cognitive processing may reflect momentary changes in brain activation that are directly related to task-induced changes in cognitive capacity. A variety of lines of experimental evidence support this hypothesis.

Perceptual Detection

Even the apparently simple processes of sensory perception place processing demands upon the human brain that can be measured by changes in the diameter of the pupil. For example, Hakerem and Sutton (1966) measured pupillary responses to light flashes at intensities near the limits of visual perception. These visual stimuli were too weak to elicit the well-known pupillary constriction to light and were in fact only barely perceptible, being reported as seen on only 50 percent of the trials. There was no pupillary dilation following visual stimuli that were not detected by the viewer, nor did dilations appear if viewer was not asked to attempt to discriminate the weak flashes. But if a discrimination (flash present or absent) was required and a flash was detected, a clear pupillary dilation appeared. This Hakerem and Sutton believed reflected the cortical demands for activation necessary to process the detected stimulus.

We have recently completed a similar set of experiments on the perception of weak acoustic signals and have found very similar results (Beatty, 1975). In one of these studies listeners attempted to detect a weak tone against a background of acoustic noise which was in fact present on only one half of all trials. When the exact time that the signal might appear was uncertain, no dilations were observed in the absence of a signal, or in the presence of an undetected signal. As in Hakerem and Sutton's experiment, the pupillary dilation indicating cortical activation occurred only when a presented signal was actually detected by the listener. These dilations occur with great reliability, indicating that the activation changes that they reflect are a constant accompaniment of perceptual processing. In fact, it was possible to predict the listener's judgment from the pupillary data alone with between 66 and 92 percent accuracy. Regular changes in nervous system activation appear to accompany even the simplest acts of sensory registration and decision.

Perceptual Discrimination

More difficult perceptual discriminations place greater demands upon the human brain that are reflected in increased levels of task-induced activation. For example, in a tone discrimination task in which the listener must decide whether the second of two tones is higher in pitch than the first, the degree of dilation following the presentation of the comparison tone varies directly as a function of task difficulty (Kahneman & Beatty, 1967). The standard tone in that experiment was always a 850 Hz (cycle per second) sine wave; the comparison tones ranged from 820 to 880 Hz in 6 Hz steps. Maximal dilations were observed following comparison tones of 850 Hz (an impossible discrimination). The greater the difference in frequency between standard and comparison, the easier was the discrimination (as measured by percent errors) and the smaller was the dilation observed in the decision interval following the presentation of the comparison tone.

Short-term Memory

Perhaps the most striking data on the relations between activation and cognitive processing comes from the study of serial short-term memory. In these experiments, subjects are presented with strings of items which they are to recall in strict serial order after a few seconds delay. Retaining a new telephone number while dialing is one example of a serial short-term memory task that is common in everyday life. Such tasks are resource-limited (Norman & Bobrow, 1975), in that the number of items that might be held in short-term memory for immediate recall reflects limits in the subject's capacity to process information.

In the first experiment pupillometrically measuring activation in serial recall (Kahneman & Beatty, 1966) five undergraduate students listened to strings of between 3 and 7 digits (the approximate limit of immediate memory for digit strings) presented at the rate of 1 per second. After a 2 second pause, they repeated back each string at the same rate. Figure 1 presents these data. Since the strings were of different length, trial duration also varied between conditions. Therefore, the data are aligned at the pause, with the beginning of presentation and the termination of response indicated on each curve by slash markers.

Several points emerge from these data. First, the pupil dilates as each digit is presented, reaching a maximal dilation after all digits are presented. Second, as each item in the string is reported by the listener, and the momentary load on immediate memory decreases, the pupil constricts, and returns to its initial level as the last digit is reported. Third, the amount

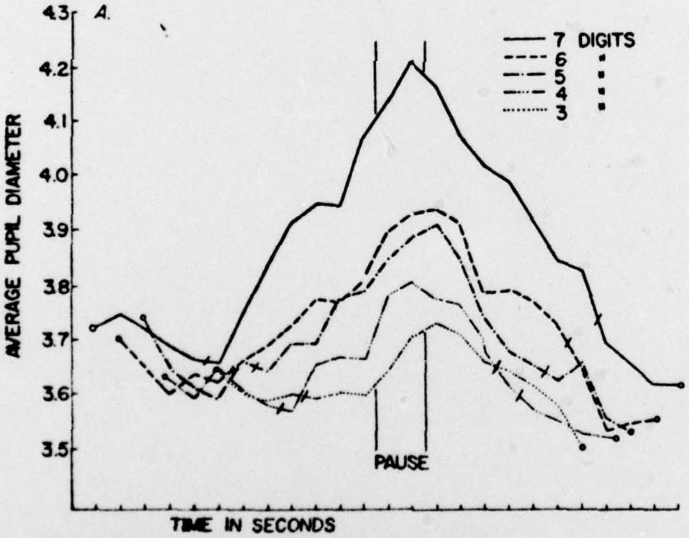


Figure 1. Average pupillary diameter in millimeters during presentation and recall of strings of 3, 4, 5, 6, or 7 digits. Slash marks on the left of the figure indicate the start of digit presentation and those on the right indicate the end of the subject's report. These curves are of different lengths, since digits were presented and reported at a constant rate of 1/sec. For this reason, the curves from all conditions are centered about the 2 second pause between stimulus presentation and subject report. (From Kahneman & Beatty, 1966, in Science, Vol. 154, No. 3756, pp. 1583-1585, with permission of the publisher.)

of dilation at the pause between digit input and output is a monotonic function of the number of items held in immediate memory. These data strongly suggest that pupillary dilation varies directly with momentary cognitive load.

If these pupillometric changes reflect processing load in the serial memory task, then the slope of the function should increase when more difficult items are used in the test. A second portion of the experiment compared both performance and activation functions for strings of four digits, four words and a transformation of four digits (adding 1 to each of the presented digits in report). These latter two tasks are more difficult than the simple digit task: In pre-experimental testing of these subjects mean digit span was 7.8 items. Thus, these three tests should differ in processing load, with larger dilations occurring for each item of the more difficult materials. Figure 2 presents the pupillometric data for this portion of the experiment. Both the slope and the maximal dilation on each of the three tests reflect the level of processing load associated with the item difficulty. Larger dilations are present for the storage of items requiring greater processing capacity.

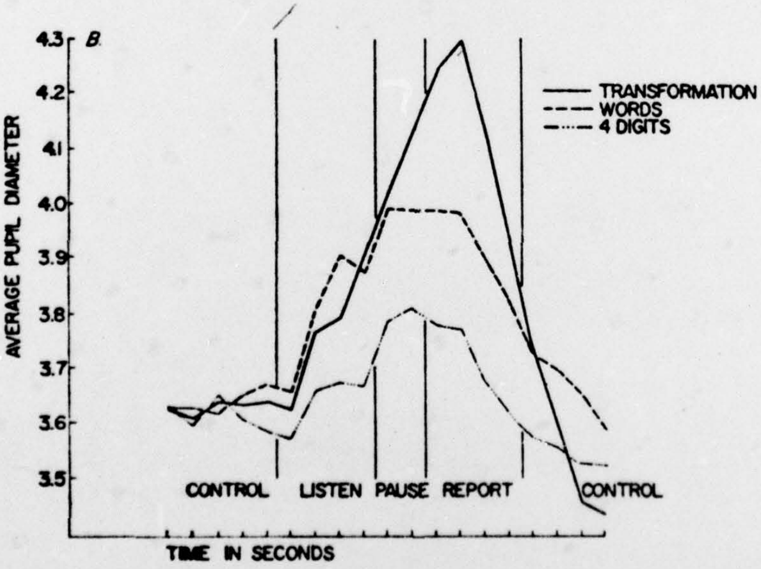


Figure 2. Average pupillary diameter in millimeters during presentation, pause and report of four digits, four words, and the transformation of a string of four digits by adding one to each digit heart before report. (From Kahneman & Beatty, 1966, in Science, Vol. 154, No. 3756, pp. 1583-1585, with permission of the publisher.)

Similar activation patterns appear when material is retrieved from permanent memory and organized in immediate memory for serial report. In one experiment (Beatty & Kahneman, 1966), for example, subjects were required to recall a familiar telephone number when presented with a one-word name associated with that number, such as "home" or "office", and to report that number at a one digit per second rate. In this situation the pupil immediately dilated following the memory cue as the telephone number was retrieved and prepared for report. The magnitude of this dilation was larger than that seen in the same subjects when presented with a string of 7 unfamiliar digits for serial recall. The difference may be related to the load imposed in retrieving information from permanent memory. During report, pupillary diameter decreased with each digit spoken, returning to baseline diameter as the last digit of the telephone number was reported (see Figure 3).

Thus in serial memory tasks processing load is not stationary or fixed, but varies from second to second as the number of items that must be held in immediate memory increases and decreases. The pattern of pupillary dilation accurately reflects these shifting demands. Further when item difficulty is increased, the magnitude of the activation changes also increases.

Problem Solving

In problem solving, as in perceptual and memory tasks, phasic activation changes may be measured pupillometrically that appear to be related to fundamental aspects of task-related information processing. For example, Hess and Polt (1964) obtained pupillary measurements as subjects mentally solved simple multiplication problems. After presentation of each problem, pupillary diameter slowly increased, reaching maximal dilation immediately before solution. Following solution and report, the pupil rapidly returned to its initial diameter. The extent of dilation at solution was a function of presumed problem difficulty or processing load: An average dilation of 10.8 percent was reported for the simplest problem (7 x 8) as compared with 21.6 percent for the most difficult (16 x 23). Dilations to problems of intermediate difficulty fell between these two extremes.

Payne, Parry and Harasymiw (1968) report a similar relationship between pupillary dilation and difficulty in mental multiplication problems. Four levels of problem difficulty were employed, in which a single-digit multiplier was used with a one to four digit multiplicand. As in the Hess and Polt experiment, a pupillary dilation appeared in the interval between

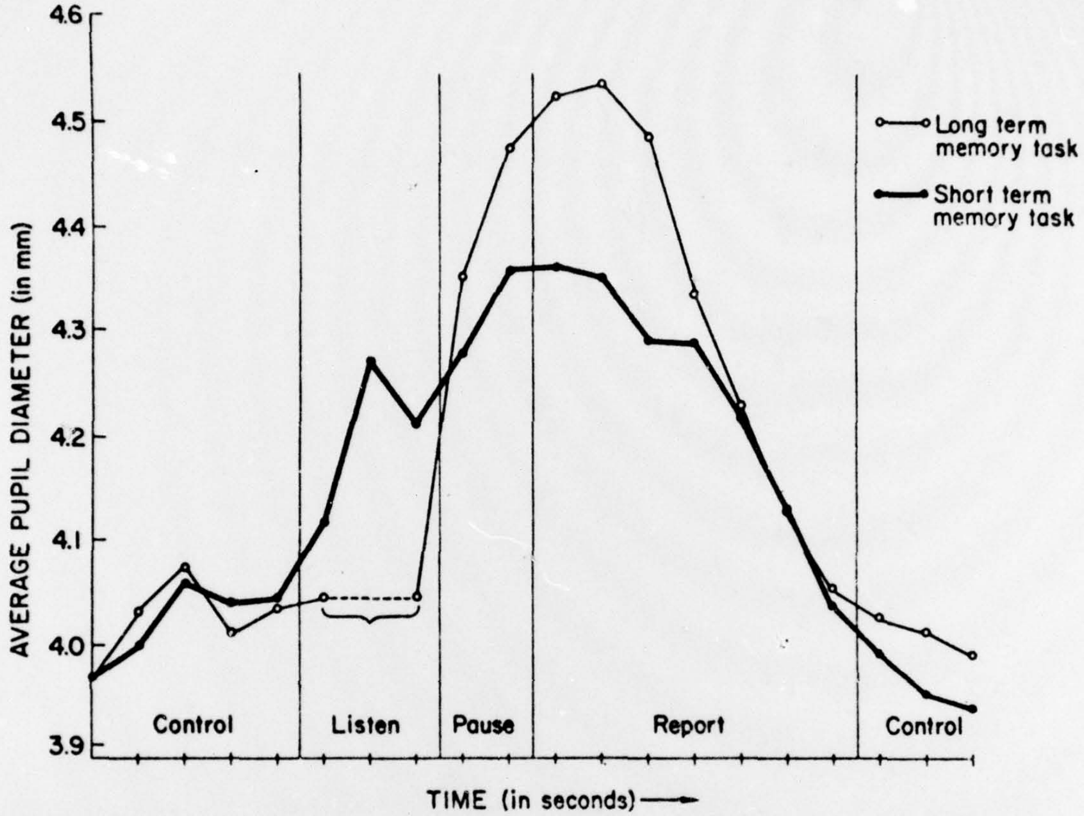


Figure 3. Average pupillary diameter during presentation and report of seven-digit telephone numbers from long-term and short-term or immediate memory. Stimulus presentation required two seconds longer in the short-term memory condition, in which the entire string of digits was read to the subject, than in the long-term memory condition, in which a single word such as "home" or "office" was used to identify the digit string for report. For this reason, the long-term memory function is broken above the trace, with both points representing the same pupillary measurement. (From Beatty & Kahneman, 1966, in Psychonomic Science, Vol. 5, No. 10, pp. 371-372, with permission of the publisher.)

problem presentation and report of solution, the degree of dilation being a monotonic function of problem difficulty. The largest difference in dilation appeared between difficulty level 1 and 2. Rather small increases in mean dilation were observed between levels 2, 3, and 4, although total processing time increased in the expected manner. Pupil data suggest that rather different internal processes may be operating in problems with single digit as compared with multiple digit multiplicands. Specifically, problems with multiple digit multiplicands require that intermediate results be stored in memory as each successive digit of the multiplicand is being processed, with processing time being a function of the number of such steps necessary to complete the problem.

The conclusion from all of this is that very rapid, phasic changes in activation accompany cognitive processing. The amount of the activation appears to be directly related to the momentary level of cognitive load imposed by the information-processing task. The reliability of these activation changes suggests that they are intimately involved in complex information-processing functions. However there are no data available at present to indicate clearly the details of the relation between phasic activation changes and cortical processing; indeed, without a reasonable understanding of the cortical mechanisms involved in specific information-processing functions it is virtually impossible to propose in concrete form the role that activation might play in facilitating them. However, the knowledge that complex cortical functions appear to be activation-dependent might provide a clue for future work on the nature of cortical mechanisms mediating complex information processing in man.

SUSTAINED ATTENTION

Research on sustained attention has focused upon watchkeeping tasks, in which people are required to monitor a monotonous display for long periods of time in search of infrequent signals. Industrial inspection is one everyday example of a situation requiring sustained attention. Radar monitoring at sea and long-distance freeway driving are others. In such tasks, performance usually deteriorates as a function of time spent continuously working. These tasks have been termed "vigilance" tasks. The assumption underlying much research on sustained attention is that performance is limited by a decline of nervous system "vigilance" (a British term that is roughly equivalent to the American "activation"). The activation hypothesis predicts that performance should deteriorate as the level of nervous system activation declines over time in the task. There is a reasonable body of evidence that supports the idea that the failure of sustained attention under such conditions is the result of a steady decline in nervous system activation. Most of this evidence comes from correlational experiments, in which both performance and brain activation are measured concurrently as a person performs a vigilance-type task for prolonged periods.

Of the various physiological measurements of activation, the most interesting for our purposes is the electroencephalogram or EEG. The EEG (see Chapter 1) is a recording of brain activity made from electrodes placed upon the scalp. For this reason, The EEG cannot reflect the individual patterns of firing of single cortical cells, or even small groups of such cells. The electrical signals recordable from the human scalp reflect simultaneously occurring electrical events in very large numbers of neurons located between the recording electrodes. (In addition, other electrical signs of bodily processes such as skeletal muscle activity or contraction of the heart muscles may appear in the EEG tracing, but with careful recording techniques, these sources of electrical activity can largely be removed from the EEG.) EEG recordings have proven to be very useful as indicators of the general state of cortical activation, in discerning the various states of sleep and indexing the relative level of alertness in the waking brain (Rechtschaffen & Kales, 1968; Lindsley, 1960).

For example, in the awake and alerted human brain, the EEG picture is characterized by a pattern of low voltage fast activity, indicating desynchrony of the cortical neurons that generate the EEG (see Figure 1.9). Such a pattern often alternates with periods of synchronous higher voltage activity at about 10 Hz, the alpha rhythm of the human brain. As alertness declines, however, desynchrony occurs less frequently and the pattern of alpha activity becomes less well-organized. Periods of lower-amplitude poorly organized activity in the theta frequencies (4 to 8 Hz) may then begin to appear.

Groll (1966), measured various indicators of nervous system activation including EEG, as volunteers performed a 90 minute sequential brightness discrimination task while laying supine, a condition that is likely to produce decreasing activation over time. Groll reported that both the percentage of correct detections and the average EEG frequency decreased as the monitoring task progressed. This is in keeping with the idea that sustained attention depends upon the maintenance of an appropriate level of activation in the brain. Further, Groll reported differences in the EEG pattern in the period immediately preceding signals that were correctly detected and signals that were missed. The mean EEG frequency preceding detections tended to be in the alpha range, whereas theta activity appeared in the EEG before misses. This suggests that the momentary state of cortical activation is related to the efficiency with which the brain can process environmental information.

Similar findings had previously been reported by Williams (Williams et al., 1962) for sleep-deprived persons exposed to conditions of monotonous monitoring requiring sustained attention, although the relation between theta activity in the posterior cortex and performance was not apparent under rested conditions. This discrepancy may result from the fact that Williams used visual methods of EEG scoring, which are less sensitive and less accurate than the more modern computer-aided techniques of EEG classification. However, not all investigators have found this theoretically predictable relation between increases in posterior theta activity and performance decrement. Daniel (1967), in an experiment that remains anomolous and contradictory, found less theta activity preceding missed signals than correctly detected ones.

One difficulty with all of these experiments is that they rely upon correlations between brain activity and behavior that unfold during prolonged periods of monotonous activity. The validity of the relation between brain activation and vigilance performance would be more firmly established if one could independently regulate the level of alertness in the observer while performing a vigilance-type task. One possible experimental approach to this question is to train people using operant or biofeedback techniques to control brain activation by regulating the posterior theta rhythm, which we have seen is a useful electroencephalographic indicator of the state of cortical arousal. The activation theory of sustained attention predicts that EEG regulation should maintain attention and prevent the vigilance decrement in subjects trained to suppress posterior theta frequency activity, whereas regulation should degrade performance and further impair performance in subjects previously trained to increase theta activity.

In collaboration with James O'Hanlon we undertook an experiment using operant regulation of the EEG in an attempt to gain a better understanding of the physiological basis of sustained attention (Beatty, Greenberg, Deibler, & O'Hanlon, 1974). The plan of the experiment was simple: First, using operant biofeedback methods, some subjects were trained to suppress posterior theta activity and others were trained to increase it. Then all subjects were tested twice in a vigilance type task, once while using feedback to regulate their EEGs as they had previously been trained and once with the EEG unregulated. Nineteen paid student volunteers were trained to regulate the proportion of theta frequency activity in the posterior EEG using standard biofeedback and operant procedures (see Beatty & Legewie, 1977, or Schwartz & Beatty, 1977, for fuller reviews of the operant modification of physiological events). Of these, twelve were trained to suppress and 7 to increase posterior theta activity. All had achieved control within 2 one-hour practice sessions. These students were also familiarized with a simulated radar observation task, which required monitoring a visual display for a period of two hours to detect infrequently-occurring weak radar-like signals.

After this pretraining, each volunteer was tested on two monitoring sessions, one with and one without the feedback signal necessary to regulate the EEG. The results of this experiment were exactly as predicted by the activation theory of sustained attention (see Figure 4). In the absence of feedback, both groups showed a decreasing level of performance over the two-hour period of the watch. When tested with feedback, however, the two groups behaved very differently. No vigilance decrement or impairment of performance occurred during the task for subjects trained to suppress EEG theta, whereas an increased vigilance decrement appeared for those subjects trained to increase theta activity. In other words, when operant procedures are employed as an independent means of regulating the level of cortical arousal, as indexed by the proportion of theta frequency activity in the posterior EEG, behavioral performance in a sustained attention or vigilance task is systematically affected. Operantly maintained cortical activation or alertness abolishes the vigilance decrement whereas operantly induced cortical deactivation acts to further degrade performance

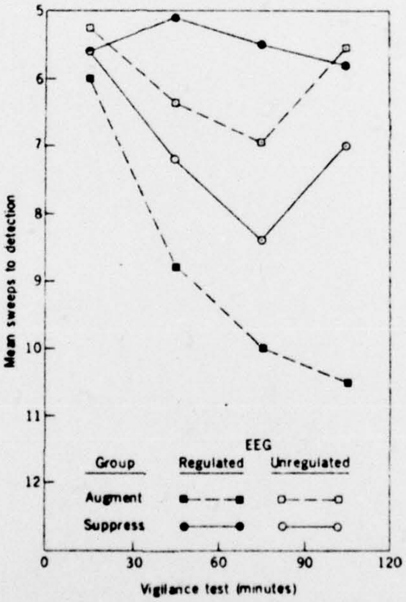


Figure 4. Mean time required to detect a target (indicated as the number of 6-second sweeps of the radar display required before detection) as a function of time in the vigilance test for the theta augment and the theta suppress groups with EEG regulated and unregulated. Notice that the ordinate (vertical) scale is inverted. Theta suppression appears to improve performance and theta augmentation degrade performance with respect to the EEG unregulated conditions. (From Beatty, Greenberg, Deibler, & O'Hanlon, 1974, in Science, Vol. 183, pp. 871-873, with permission of the publisher).

in a task requiring sustained attention. These findings, together with the previously observed correlation between decline in performance as a function of time on the task and a decline in physiological indicators of cortical activation, lend substantial support to the link proposed between sustained attention and the tonic level of nervous system activation.

SOME DIFFICULTIES

The activation theories of intensive and sustained attention have received considerable empirical support, as the experimental evidence discussed above would indicate, but they are not without some problems. First, although both intensive and sustained attention are closely related to brain activation processes, the interrelations between phasic activation and tonic activation are far from clear. Tonic and phasic activation processes appear to operate with some degree of independence. For example, over a short series of auditory discrimination trials, a tonic measure of activation may decline markedly, whereas a phasic measure reflecting task-induced activation changes occurring on each trial may remain constant from beginning to end (Kahneman & Beatty, 1967). These two kinds of processes are clearly complex and a similar level of complexity is required for any general theory of brain activation treating both kinds of data.

Second, the mechanism by which brainstem activation processes affect the efficiency of cortical information processing remains puzzling. At the cortical level, activation means something other than simple excitation; the average rate of firing in most cortical neurons does not increase markedly during activation. Rather, it is the patterning of firing that appears to be changed. In visual cortex, for example, during activation, cells become more responsive to sensory stimulation without grossly changing their firing rates (Evarts, 1963). The way in which this reorganization is accomplished is presently unknown.

Third, the various signs taken as indicators of nervous system activation are not always in perfect agreement. Activation therefore cannot be a unitary process and care must be exercised to specify exactly what measures of nervous system activity are taken as indicators of activation in any particular instance. Yet it is clear that brain activation mechanisms and behavioral attention processes are intimately related. The task is to explore more deeply and to clarify more exactly the nature of these relationships.

REFERENCES

Beatty, J. Prediction of detection of weak acoustic signals from patterns of pupillary activity preceding behavioral response. UCLA Technical Report, 27 May 1975.

Beatty, J., Greenberg, A., Deibler, W. P., & O'Hanlon, J. F. Operant control of occipital theta rhythm affects performance in a radar monitoring task. *Science*, 1974, *183*, 871-873.

Beatty, J., & Kahneman, D. Pupillary changes in two memory tasks. *Psychonomic Science*, 1966, *5*, 371-372.

Beatty, J., & Legewie, H. *Biofeedback and behavior*. New York: Plenum, 1977.

Broadbent, D. E. Stimulus set and response set: Two kinds of selective attention. In D. I. Mostofsky (Ed.), *Attention: Contemporary theory and analysis*. New York: Appleton-Century-Crofts, 1970.

Daniel, R. S. Alpha and theta EEG in vigilance. *Perceptual and Motor Skills*, 1967, *25*, 697-703.

Davies, D. R., & Tune, G. S. *Human vigilance performance*. New York: American Elsevier, 1969.

Egeth, H. Selective attention. *Psychological Bulletin*, 1967, *67*, 41-57.

Evarts, E. V. Photically evoked responses in visual cortex units during sleep and waking. *Journal of Neurophysiology*, 1963, *26*, 229-248.

Goldwater, B. C. Psychological significance of pupillary movements. *Psychological Bulletin*, 1972, *77*, 340-355.

Groll, E. Central nervous system and peripheral activation variables during vigilance performance. (In German, English summary). *Zeitschrift fur Experimentelle und Angewandte Psychologie*, 1966, *13*, 248-264.

Hakerem, G., & Sutton, S. Pupillary response at visual threshold. *Nature*, 1966, *212*, 485-486.

Hess, E. H., & Polt, J. M. Pupil size in relation to mental activity during simple problem-solving. *Science*, 1964, *140*, 1190-1192.

James, W. *The principles of psychology*. New York: Dover, 1890.

Janisse, M. P. (Ed.) *Pupillary dynamics and behavior*. New York: Plenum, 1974.

Kahneman, D. *Attention and effort*. Englewood Cliffs, New Jersey: Prentice-Hall, 1973.

Kahneman, D., & Beatty, J. Pupil diameter and load on memory. *Science*, 1966, *154*, 1583-1585.

Kahneman, D., & Beatty, J. Pupillary responses in a pitch-discrimination task. *Perception & Psychophysics*, 1967, *2*, 101-105.

Kahneman, D., Tursky, B., Shapiro, D., & Crider, A. Pupillary, heart rate, and skin resistance changes during a mental task. *Journal of Experimental Psychology*, 1969, *79*, 164-167.

Karlin, L. Cognition, preparation, and sensory evoked potentials. Psychological Bulletin, 1970, 73, 122-136.

Kellaway, P., & Petersen, I. (Eds.) Automation of clinical electroencephalography. New York: Raven, 1973.

Lindsley, D. B. Attention, consciousness, sleep and wakefulness. In J. Field (Ed.), Handbook of physiology (Volume III). Washington, D.C.: American Physiological Society, 1960.

Loewenfeld, I. E. Mechanisms of reflex dilations of the pupil. Documenta Ophthalmologica, 1958, 12, 185-359.

Mackworth, J. F. Vigilance and habituation. Baltimore: Penguin, 1969.

Mackworth, J. F. Vigilance and attention. Baltimore: Penguin, 1970.

McCallum, W. C., & Knott, J. R. (Eds.) Event-related slow potentials of the brain: Their relations to behavior. Amsterdam: Elsevier, 1973.

Moray, N. Listening and attention. Middlesex, England: Penguin, 1969. (a)

Moray, N. Attention: Selective processes in vision and hearing. London: Hutchinson Educational, 1969. (b)

Moruzzi, G., & Magoun, H. W. Brain stem reticular formation and activation of the EEG. Electroencephalography and Clinical Neurophysiology, 1949, 1, 455-473.

Mostofsky, D. I. (Ed.) Attention: Contemporary theory and analysis. New York: Appleton-Century-Crofts, 1970.

Norman, D. A. Memory and attention. New York: Wiley, 1976.

Norman, D. A., & Bobrow, D. G. On data-limited and resource-limited processes. Cognitive Psychology, 1975, 7, 44-64.

Payne, D. T., Parry, M. E., & Harasymiw, S. J. Percentage pupillary dilation as a measure of item difficulty. Perception & Psychophysics, 1968, 4, 139-143.

Picton, T. W., & Hillyard, S. A. Human auditory evoked potentials. II: Effects of attention. Electroencephalography and Clinical Neurophysiology, 1974, 36, 191-199.

Posner, M. I. Psychobiology of attention. In M. S. Gazzaniga & C. Blakemore (Eds.), Handbook of psychobiology. New York: Academic Press, 1975.

Rechtschaffer, A., & Kales, A. Manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. USPHS. Washington, D.C.: U.S. Government Printing Office, 1968.

Schwartz, G. E., & Beatty, J. Biofeedback: Theory and research. San Francisco: Academic Press, 1977.

Stroh, C. M. Vigilance: The problem of sustained attention. Oxford: Pergamin Press, 1971.

Swets, J., & Kristofferson, A. B. Attention. Annual Review of Psychology, 1970, 21, 339-366.

Tecce, J. J. Attention and evoked potentials in man. In D. I. Mostofsky (Ed.), Attention: Contemporary theory and analysis. New York: Appleton-Century-Crofts, 1970.

Tecce, J. J. Contingent negative variation (CNV) and psychological processes in man. Psychological Bulletin, 1972, 77, 73-108.

Treisman, A. M. Strategies and models of selective attention. Psychological Review, 1969, 76, 282-299.

Williams, H. L., Granda, A. M., Jones, R. C., Lubin, A., & Armington, J. C. EEG frequency and finger pulse volume as predictors of reaction time during sleep loss. Electroencephalography and Clinical Neurophysiology, 1962, 14, 64-70.