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JULY 1, 1974 TO DECEMBER 31, 1975

SELF-REGULATION AS AN AID TO HUMAN EFFECTIVENESS

and

BIOCYBERNETICS TECHNOLOGY AND BEHAVIOR

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This Annual Progress Report includes a summary and overall conclusions from the 5-year research program concerned with Self-Regulation as an Aid to Human Effectiveness. While the findings clearly demonstrated that self-regulation of most physiological variables was possible, the control of these various physiological measures did not consistently lead to enhanced performance. The report also includes the current subcontracts awarded under the Biocybernetics Technology and Behavior program. The research goals and first year's progress of each subcontractor are also presented.

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and

BIOCYBERNETICS TECHNOLOGY AND BEHAVIOR

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ABSTRACT

The goal of the self-regulation research program was to determine the relevance of physiological processes and internal states for the enhancement of effective performance.

This report summarizes the work done by subcontractors awarded subcontracts under the contract awarded the San Diego State University Foundation under ARPA Order No. 1595 dated March 6, 1970. The report, Part B, also lists the work being supported in the area of biocybernetics, but the major portion of the report reviews the work done in the area of self-regulation.

At the completion of the fifth and final year, the results of work by the various subcontractors in the self-regulation of brain, cardiovascular, vasomotor, and muscle activity indicated that it was possible to regulate activity in each of these areas by appropriate biofeedback procedures. On the basis of extensive and intensive work by the various researchers, however, it is clear there is no easy and powerful key available in biofeedback for significant enhancement of performance. Reliable relations between internal events and performance have not been convincingly demonstrated in this series of studies. The results of this research program offer little support for the initial goal of using voluntary regulation of physiological events to enhance performance. The few interesting laboratory results on simple tests evaporated when more complex operational tasks were performed outside the laboratory. Several conclusions offer themselves as a result of this body of work: First, it seems that biofeedback offers much less powerful and robust self-control over certain internal physiological events than many researchers believed on the strength of early anecdotal evidence. Second, it is extremely difficult, if not impossible, to train subjects to regulate nervous system events to a level contrary to the best interests of their own physiology. Third, effects have been, in general, obtainable only in physiologically appropriate directions, and attempts to develop ability to respond autonomically

contrary to spontaneous tendencies have met with very limited success. And fourth, the various investigators in this research program have failed to identify specific configurations of physiological events which have unique and reliable concomitance with specific performance or psychological states, and which can be controlled for the purpose of eliciting these behaviors. Until further research establishes a discrete relationship between specific physiological events and performance, or until new techniques for biofeedback become more efficient, further efforts toward the utilization of self-regulation to performance enhancement do not appear reasonable.

The Biocybernetics Program described in Part B is intended to develop highly interactive, closely coupled man/machine interfaces for the extension and enhancement of human performance. One of the major goals is to provide the ability to control a computer by direct entry of nonverbal bioelectric signals. The result, ideally, will be a man-computer system so highly interactive, and so closely and rapidly responsive in such fine detail to the wishes and needs of the user, that it serves as an extension of the user's own capabilities.

To accomplish this goal, seven subcontracts have been awarded to conduct research on magnetoencephalography, brain wave syntax development, brain analysis of verbalization, relation of pupillary response and performance, and for the development of advanced statistical methodology for the analysis of brain wave events. The research plans and progress are briefly reviewed in Part B.

INTRODUCTION

This is the terminal progress report under the contract awarded by the Office of Naval Research to the San Diego State University Foundation under ARPA Order No. 1595 dated March 6, 1970. The duration of the contract was from March 6, 1970, to December 31, 1975. Over the period of this contract, subcontracts were awarded to 16 subcontractors. These subcontractors are listed in Appendix 1.

During Fiscal Year 1975, the contract was modified to support research concerned with the development of highly interactive, closely coupled man/machine interfaces for extension and enhancement of human performance. This program was part of a larger ARPA-sponsored research program under the general heading of Biocybernetics.

This report will initially summarize the major self-regulation research program under this contract and then briefly list the specific research goals of the subcontractors added as a part of the biocybernetics research. The ARPA-sponsored research at the Naval Health Research Center, involved with self-regulation of brain activity, is included to provide a more complete picture of the total ARPA-sponsored research program.

A. Self-Regulation as an Aid to Human Effectiveness

The goal of this research program was to investigate whether teaching individuals to control physiological variables could enhance performance and whether self-regulation could reduce the performance decrement frequently observed in highly stressful situations. The general experimental plan was (1) to offer subjects control over various cardiovascular, EMG, and brain wave events via biofeedback, (2) to observe correlations between one or more of these physiological variables and performance, (3) to induce stress and observe the performance decrement, and (4) to determine whether through self-regulation the stress-related performance decrement could be ameliorated. Generally, the proposition to be tested held that individuals who gain control over their internal physiology concomitant with behavioral events or affective states will perform better and have more control over the behaviors or states.

Consider the case of a pilot whose airplane has been damaged and is in danger of crashing, and who is in a state of near panic. Suppose he voluntarily lowers his heart rate, reduces his blood pressure, and partially relaxes his temporalis muscles. Will he then feel and behave in a more calm and effective manner? Or, if a trainee is taught to emit a particular pattern of brain waves associated with receptivity to new information, will he, by voluntarily emitting this EEG configuration, be able to make more efficient use of information a computer-assisted instruction system can offer him? Biofeedback appeared to offer a way to allow subjects to vary heart rate or other physiological responses without the use of drugs (which may have direct effects on feeling-states via CNS action) or external stimuli such as electric shock (which obviously does affect feeling-states). The ability to control specific autonomic responses would provide a test of their relation to subjective emotional states and to cognitive and motor performance.

1. Brain Activity

Perhaps because of its pre-eminence in biofeedback research circa 1970, self-regulation of alpha activity initially received most attention. Work by Paskewitz and Orne (1973), however, quickly raised questions as to the generally accepted simplicity of the alpha-feedback process. In their work, it soon became clear that eyes-open alpha-feedback training led to an enhancement of alpha density only in the presence of ambient light. In total darkness, no alpha enhancement over baselines was observed in numerous training sessions. While Paskewitz and Orne's subjects did, with feedback, increase alpha density in the presence of ambient light, they never exceeded resting non-drowsy alpha baselines obtained in total darkness. Paskewitz and Orne postulated that, by feedback training, subjects were able to overcome partially the inhibitory effects of ambient light on alpha activity. In other individuals, they hypothesized that feedback might overcome the alpha-inhibiting influence of anxiety, concentration, etc. They further speculated that the subjective effect of alpha enhancement would be directly related to the inhibitory influence that was overcome. Such reasoning, they felt, would explain the varying subjective experiences reported by subjects while experiencing alpha enhancement.

Kamiya (1969) had suggested that pleasant feelings of relaxation accompany increases in alpha. Nowlis and Kamiya (1970) implied that alpha enhancement aided task performance, and Green, Green, and Walters (1970) asserted that alpha enhancement improved delayed recall. Enhanced alpha appeared to raise the pain threshold (Gannon & Sternbach, 1971), facilitate extrasensory perception (ESP) (Honorton, Davidson, & Bindler, 1971), and lead to a decreased need for sleep (Regestein, Buckland, & Pegram, 1973). For some scientists, as for many laymen, further research was unnecessary; it was a proven scientific fact that high alpha universally enhanced both work and play.

Unfortunately, results from the laboratories of Joe Kamiya, University of California, San Francisco, Jackson Beatty, UCLA, and the Naval Health Research Center, San Diego, have not supported this view of alpha as a panacea. The findings of Paskewitz and Orne constitute an important caveat! Self-regulation of alpha activity is not a substitute for sleep, nor can the deleterious effects of acute sleep loss on performance and mood thus be ameliorated (Hord, Tracy, Lubin, & Johnson, 1975; Hord, Lubin, Tracy, Jensma, & Johnson, 1976).

Beatty (1973) found no relationship between occipital alpha feedback and two measures of information-processing capacity: short-term memory for digits and choice-reaction times. In this study, Beatty selected his 5 best alpha-producing subjects. An on-line computer was employed to scan the subject's EEG and to deliver task information to the subject on each trial. Each trial was begun by an instruction for the subject to produce either a high alpha state or a beta state. When the desired EEG pattern was maintained for 3 sec, the digits were presented by the computer-controlled display apparatus.

The data indicated that there was essentially no detectable difference in the efficiency with which most of the subjects processed symbol strings when those strings were presented in periods of occipital alpha or beta frequency activity.

In the choice-reaction paradigm, subject watched for a signal on a screen and, when it appeared, he was to depress a button indicating its identity as quickly and as accurately as possible. Beatty felt that if cortical synchrony is related to information-processing efficiency, then it should show its effect in the choice-reaction task. This study was again under computer control, and when the necessary EEG state had been maintained for 2 sec, the stimulus was presented. Three of 5 subjects showed consistently shorter reaction times when the stimulus occurred during desyncrhony than during synchrony.

Kamiya, like Beatty, found EEG activity unrelated to both memory for words and a simple reaction-time test. In another study, Kamiya (1972) attempted to determine whether subjects trained to control alpha amplitude would show improvement in performance tasks if break periods from the tasks were used to maintain high alpha amplitude. The reasoning underlying this hypothesis was that alpha is often regarded as indicative of a resting or idling condition which may be characteristic of rest periods from performance tasks. Five young male adults were given a battery of performance tasks with 4-min break periods between each task. The control group was told merely to wait for 4 min between tasks while the experimental group was trained to produce alpha and received 4 min of alpha feedback between tasks. The tasks were verbal auditory vigilance, rod and frame, Guilford creative intelligence, visual memory, mental arithmetic, digit memory span, and tone tracking. The results were negative. Kamiya concluded that the self-regulated high alpha break period did not facilitate task performance.

Martin Orne and his associates (1975) explored the ability of subjects to maintain a high alpha state while performing cognitive tasks. Nine well-trained subjects were able to maintain the alpha activity while counting backwards by one, but counting backwards by seven significantly blocked alpha when compared to non-task trials. Complexity of the task, subject's ability to perform the task, and level of effort by the subject were all related to the degree of alpha blocking during the tasks. In a series of related studies, Orne et al. (1975) were unable to find a relationship between alpha training and performance on various other cognitive tasks. Further, Orne and Paskewitz (1974) concluded, from an unsuccessful attempt to discover a relationship between alpha and anxiety induced by threat of painful electric shock, that their data "not only raise theoretical questions about the meaning of alpha density, but also challenge the widely accepted rationale for using alpha feedback training as a means of teaching individuals control over their own levels of anxiety" (p. 460).

Thus, enhanced alpha activity does not prevent sleep-loss effects or substitute for sleep (Hord et al., 1975, 1976), is not related to memory or choice-reaction performance (Beatty, 1973), does not provide a recuperative break period (Kamiya, 1972), and is incompatible with cognitive tasks requiring any degree of effort (Orne et al., 1975). With respect to self-regulated alpha and pain, Melzack and Perry (1975) used alpha feedback and hypnotic training for the control of chronic pain. They report that the combined procedures produce a substantial decrease in pain (by 33% or greater) in 58% of the patients during the training sessions. They conclude, however, that since alpha alone had no significant effect on pain reduction, the contribution of the alpha-training procedure to pain relief when combined with hypnosis was "not due to increased EEG alpha as such but, rather, to the distraction of attention, suggestion, relaxation, and sense of control over pain which are an integral part of the procedure" (Melzack & Perry, 1975, p. 452).

In contrast to these findings related to alpha activity, occipital theta (3-7 Hz), and in particular the absence of theta, was reported to be significantly associated with ability to maintain vigilance performance (Beatty, Greenberg, Deibler, & O'Hanlon, 1974). In their initial paper, it was reported that suppression of theta by operant methods enhanced monitoring efficiency whereas theta augmentation led to further degradation over a 2-hr watch period. Beatty et al. were encouraged by their theta-suppression results and stated, "This is the first demonstration, to our knowledge, of a lawful relationship between operantly regulated cortical phenomena and performance in man" (Beatty et al., 1974, p. 873).

The nature of this relation, however, turned out to be influenced by both task and subjects. In a 1-hr vigilance task, subjects trained to suppress theta performed no better than a nonfeedback group, though the theta-suppression subjects did detect signals more rapidly than subjects trained to augment theta. Because the ultimate goal of the ARPA program was to utilize laboratory findings in an operational environment on tasks of varying duration, Beatty and O'Hanlon shifted from college students to trained radar observers in their UCLA laboratory. The level of self-regulated theta suppression was less with the 11 radar observers than with college students though, like the college students, the Naval subjects required significantly fewer sweeps for target detection when theta-suppression feedback was provided (Beatty & O'Hanlon, 1975). But more troublesome was the finding that in an operational test at a nearby Naval Air Station involving 14 Naval petty officers trained as air controllers or radarmen, operant control of theta had no significant effect during a 3-hr vigilance task (O'Hanlon & Beatty, 1975).

As a further test of theta suppression, Hord, Wilson, Townsend, and Johnson (1975) studied 19 Naval subjects in a 3-hr sonar task. One group of 7 subjects used biofeedback to suppress theta activity, 7 subjects were yoked controls (each yoked control received the same tones as those of a feedback subject but had no control over the tone), and 5 subjects received no theta feedback or tones. There were no significant differences among the three groups in time to detect sonar signals or in number correctly detected.

Beatty & O'Hanlon felt that the theta-feedback procedures provided the subject with new information concerning his state of nervous system arousal, permitting him to maintain alertness in a manner not otherwise possible. In situations where there is no lowering in the level of alertness, there whould be little performance decrement and theta suppression would have little impact on performance. Such was the case in the short 1-hr vigilance task. Absence of a baseline decrement also may have been a factor in the negative results in the two Naval laboratory settings. O'Hanlon and Beatty noted that their 2 subjects who showed a performance decrement during an initial 3-hr vigilance task without contingent theta feedback showed no decrement during the second 3-hr task when contingent theta feedback was provided (O'Hanlon & Beatty, 1975).

To test further the arousal hypothesis, Morgan and Coates (1975) investigated the extent to which self-regulation of theta activity might be used to enhance performance, or at least reduce the expected performance decrement, during 48 hr of continuous performance and sleep loss. Prior to the 48-hr vigil, 9 subjects were trained to suppress theta activity and increase heart rate (HR) concurrently. The tasks were from the Multiple Task Performance Battery (MTPB) used in several studies by this group (Alluisi, 1967, 1972; Morgan & Alluisi, 1972). While subjects were able to self-regulate theta activity and HR at the beginning of the continuous-performance period, the operant suppression of theta was less effective toward the end of the 48-hr period (Hord et al. (1976) have also found that self-regulation of alpha and non-alpha activity deteriorates after one night of sleep loss). Operant control of HR showed less decrement.

Comparison of the performance of these self-regulation subjects with comparable data from an earlier group run on the MTPB showed no statistical difference in level of performance. MTPB performance was not significantly enhanced by the use of self-regulation prior to, during, or subsequent to 48 hr of continuous work and sleep loss.

In summary, whereas alpha enhancement or suppression have not been found to affect performance, theta suppression may prevent or lessen the performance decrements that are typically found in vigilance tasks of long duration. A performance decrement may be a necessary condition for the observance of any theta effect, and there are no data to suggest that theta suppression can lead to performance enhancement above initial levels.

As Beatty and O'Hanlon emphasized, the feedback technique helps subjects to become aware of changes in their own arousal level and thus alerts them to take corrective steps. It is likely that this effect--if it turns out to exhibit reliability and robustness--reflects state changes comfortably subsumed under most conceptualizations of arousal; perhaps Beatty and O'Hanlon have discovered a way to teach people to stay awake without drugs or peripheral stimulation. There are, however, no consistent data indicating that background theta activity per se (i.e., theta activity generally present and not associated with changes in arousal) is related to performance levels (Williams, Granda, Jones, Lubin, & Armington, 1962). Recent findings by the Naval Health Research Center support the conclusions of Williams et al. Theta feedback appears to allow the subject to become aware of changes in state which are reflected by changes in theta levels, rather than in theta activity per se.

2. Cardiovascular Activity

While only good things had been imputed to alpha enhancement at the start of the research program, there were serious concerns as to the levels beyond which cardiovascular activity should not be pushed, and as to the long-term effects of biofeedback-induced cardiovascular changes. As an initial part of the ARPA self-regulation project, Alan Harris and Joseph Brady were asked to determine safe limits and the possible chronic effects of operant control of blood pressure and heart rate (HR) in animals (Harris, Findley, & Brady, 1971; Harris, Gilliam, Findley, & Brady, 1973).

Following the animal work which indicated that there was little risk to human subjects, Harris and his colleagues concentrated on the operant control of HR and the relation of self-regulated increases and decreases in HR to performance (Harris et al., 1973, 1974) and to physiological variables (Stephens, Harris, & Brady, 1972; Stephens, Harris, Brady, & Shaffer, 1975).

The results of these human studies have been evaluated with respect to the extent to which (1) engaging in a concurrent task modifies self-regulatory ability, and reciprocally, (2) autonomic self-regulation of HR affects the concurrent task performance. For 19 subjects, self-regulated HR increases averaged 15 beats per minute (bpm), decreases averaged 3 bpm, with a range from 29 bpm increase to 16 bpm decrease. HR could be controlled to some extent by practically all subjects tested; HR increases were significantly easier to achieve than decreases. Significant correlations between changes in HR and blood pressure were observed, with the stronger relation appearing during the HR "increase" condition.

Subjects were tested on three kinds of tasks, ranging from a relatively simple auditory reaction-time task and a Mackworth Clock Vigilance test to mental arithmetic problems under time-limit conditions. In all cases, the task requirement had been introduced repeatedly throughout each of the self-regulation components (i.e., HR "raising," "lowering," and "rest") with problem presentations occurring on the average of approximately once per minute with a variable interval range from 15 to 95 sec. All subjects were able to perform satisfactorily on the reaction-time task without interfering with HR self-regulation and no significant differences in the reaction-time performance could be discerned as a function of the self-regulatory HR change (i.e., "raising" or "lowering").

The Mackworth Clock Vigilance task required subject to report the occurrence of skipped steps ("jumps") in the clockwise rotation of the sweep-hand on a large clock face. The vigil was maintained continuously throughout the experimental session with "clock jumps" programmed to occur on the average of once per minute during all three phases of the self-regulatory program (i.e., HR "raising," "lowering," and "rest interval"). The interaction between the Mackworth Clock Vigilance task and HR self-regulation was studied in 4 subjects during a total of 20 experimental sessions under both incentive (i.e., special performance effectiveness "pay") and non-incentive conditions. The results again showed no discernible effect either of the concurrent vigilance task upon HR self-regulation or of the self-regulation requirement upon the vigilance behavior.

In addition to the Mackworth Clock, the Continuous Performance Task (CPT) described by Rosvold, Mirsky, Sarason, Bransome, and Beck (1956) was included as another vigilance task. The CPT requires the identification of the letter "x" from among various letters presented at a 2-per-sec rate on a display in front of the subject. Correct identifications were reported by a hand-switch. As earlier studies had showed no correlation between HR changes and performance in nonstressful conditions, the task situation was modified to induce a degree of stress. The assumption was that stress would be a disruptive factor which would be reflected in HR changes. If HR were under operant control, this change in HR could be prevented or counteracted and the disruptive effects of stress on performance minimized.

Superimposed upon both the self-regulation of HR and the concurrent vigilance task performance were clicker-shock pairings which represented an additional stress factor in the environment. Each clicker presentation lasted for 1 min and terminated with an electric shock (5-15 ma for 0.5 sec) applied to the subject's lower right leg. Each subject determined his or her own "painful but tolerable" shock levels during pre-experimental instructional periods. Three such pairings were presented during a 10-min interval of HR raising, HR lowering, or rest, with and without the added concurrent vigilance task performance.

This aversive classical cardiovascular conditioning procedure was a modification of the "conditioned emotional response" or "conditioned suppression" method extensively used in animal laboratories (Brady, 1969).

A new sample of 40 subjects was initially examined for this study. Self-regulated HR increases averaged 13 bpm while HR decreases averaged 3 bpm, with a range of from 47 bpm increases to 14 bpm decreases. Thirteen subjects were used to examine the interaction of HR control and performance in the nonstressful and stressful conditions (Brady et al., in press). While accuracy of response was not affected by the experimental conditions or HR regulation, the reaction times under conditions of regulated HR lowering were clearly the longest. Those during HR raising were the shortest ($P < .05$), and reaction times in the absence of HR control fell at an intermediate value.

When the clicker-shock pairings were imposed on the task (i.e., there were 3 1-min clicker-shocks presented in a 10-min segment), there was a characteristic reduction in baseline HR. The effects of stress upon the interaction between HR self-regulation and concurrent vigilance task performance resulted in the elimination of the subject's ability to produce HR decreases, and the self-regulated HR increase effects decreased to about 7 bpm. Clearly, interactions among concurrent performance, HR self-regulation, and stress occurred.

During clicker-shock pairings, concurrent performance scores (i.e., percent correct) fell to 73% during rest intervals, and to a low of 60% during periods requiring HR decreases. During periods of self-regulated HR raising, these decrements were essentially eliminated while during self-regulated HR lowering even greater response decrements were produced. Harris et al. (1974) felt that the counteraction by HR raising of the performance decrement shown during clicker-shock pairings was a clear indication of the potential for autonomic self-regulation to provide an effective technique for the prevention of performance decrement due to aversive classical conditioning stress. The counteraction of stress-elicited HR changes by biofeedback control has also been demonstrated in monkeys (Ainslie & Engel, 1974), and the relationship of these interactions to human performance should be studied further.

Earlier, it was noted that Morgan and Coates (1975) had required their subjects to suppress theta and raise HR concurrently. The rationale for training HR increases was the finding of Harris et al. that HR increase was associated with increased accuracy and faster reaction times on the CPT. As will be recalled, Morgan and Coates found no positive effects from combined self-regulated theta suppression and HR increase during a 48-hr period of continuous performance. Moreover, in an examination of individual differences and a closer inspection of each subject's response, they found that where relations did exist between HR increase and performance, the relations were negative. A tendency appeared toward greater HR control occurring with larger performance decrements and greater theta control occurring with smaller performance decrements. Morgan and Coates felt these results suggested that "the two control functions were antagonistic in their effects on performance" (Morgan & Coates, 1975, p. 25).

Operant control of HR, especially HR increase, as a technique for enhancing human performance appears to be more promising than enhancement of alpha. Since there were no EEG data recorded by Harris et al., one can only speculate whether the poorer performance during HR lowering was a reflection of lower arousal levels and the reverse with HR increase. If this were true, HR lowering might be expected to increase EEG theta, although the findings of Morgan and Coates suggest considerable individual difference in this relationship. Further, Hord and Barber (1971) reported the relation between alpha enhancement and basal HR was not the same across subjects and that when the within-correlations over subjects were averaged, the average correlation did not differ significantly from zero.

3. Muscle Relaxation

If there is one technique that can claim precedence over all the current biofeedback techniques, it is muscle relaxation (Jacobson, 1938). Does operant control of muscle activity enhance performance in nonstressful situations and prevent performance decrement in stressful conditions? From the data produced under the ARPA program, the answer must be "no."

Stoyva and Budzynski (1973) examined the effects of muscle-relaxation training on tasks involving either complex decision-making or simple sensory motor activity. Performance under stress, and in the recovery phase after stress, was examined. The most severe test was in a complex decision task under stress. Here subjects were presented with visual slides of intelligence test problems (Cattell Culture-Fair Test) in which the missing figure in a series of geometric figures must be inferred. While engaged in this task, loud distracting noises were presented over headphones and, at arbitrary intervals, colored slides of a gory and disturbing automobile accident were presented in place of the problems. The objective was to determine whether subjects trained in moderating their arousal levels by means of self-regulated muscle relaxation would perform better (make more correct decisions) than subjects who lacked such training. No significant differences were found. In related experiments, these investigators also found no enhancement of performance in (1) complex decision-making, (2) a serial 7's task, (3) stylus steadiness, (4) pursuit rotor performance, or (5) ability to maintain a sleep state in a distracting environment.

In an operational test of the effectiveness of muscle relaxation in overcoming stress-induced physiological and performance changes, Smith (1975) examined 36 subjects in a hyperbaric chamber. Three performance environments were used: (1) a control condition, involving no hyperbaria simulated or real, open hatches to the chamber, and a nonstressful briefing; (2) an experimental condition, with simulated hyperbaria to 100 ft and a briefing designed to induce anxiety; and

(3) a second experimental condition involving actual hyperbaria to 30 ft for induction of modest physiological stress plus simulated hyperbaria to 100 ft.

Nine subjects were given 8 weeks of self-regulation EMG biofeedback training and were encouraged to use this training to maintain a state of physiological relaxation throughout their chamber experience. A second group of 9 subjects was given 2 weeks of simulated (and largely recognized as such) self-regulation training and was also asked to use their training to maintain a state of relaxation during the study. A third group of subjects was given no preliminary training but was asked to relax physiologically as much as possible throughout the study. The fourth group had no preliminary training and was given no specialized instructions with regard to relaxation. All subjects were told casually to "sit back and relax" at several points when physiological measures were taken.

Recording of EMG, HR, and blood pressure was done periodically throughout the simulated and actual pressurization, and during an initial phase for the first and fourth groups. Immediately upon stabilization of the chamber, all subjects were given the TODAY form of the Multiple Affect Adjective Checklist (MAACL) to assess their level of anxiety, depression, and hostility. During this time, the subjects were again asked to relax and recordings were made of all three physiological parameters. The remaining 30 min of each chamber run were utilized for performance measurement interrupted for ventilation and physiological recording. Performance measures included a "Mathematics Aptitude Test" and the "Ship Destination Test" designed to assess general reasoning ability, which has been shown to decline under physical stress (Smith & Armstrong, 1973). An apparently operational vigilance task was superimposed over these cognitive activities to reduce perceptual narrowing and provide a more realistic environment. This task consisted of monitoring the depth indicator in the chamber and informing the experimenter of any deviations from 100 ft, greater than ± 5 ft. Such deviations were programmed to occur twice during each trial. A detailed debriefing followed the chamber experience, including "dehoaxing" the subject with regard to any deception employed.

All subjects receiving biofeedback training showed a significant decrease in EMG levels. Simulated training did not "fool" the subjects into believing they had been trained, nor did it appreciably affect their general physiological state. All subjects, however, whether under simulated or actual hyperbaria, perceived themselves to be at a pressure equivalent to a depth of at least 50 ft and some subjects assumed their depth to be 100 ft. The effectiveness of this stress was further manifested by elevated physiological parameters and depressed performance measures. There was, however, no apparent benefit of biofeedback training in the suppression of physiological response to stress (subjects who had received biofeedback training reported difficulty in concentrating on self-regulatory activity during the stressful "dive"), nor did biofeedback training enhance performance on any of the tasks. In his summary, Smith concluded, "based upon the limited data available in this study, one can conclude that the relatively mild form of perceived physical threat created in this highly controlled laboratory environment is sufficient to produce expected increments in physiological functions and a concomitant decrement in performance. However, biofeedback training as conducted for this study, while effectively reducing physiological levels in low stress situations appears ineffective for the control of physiological functions or the enhancement of performance under perceived physical threat stress" (Smith, 1975, p. 28).

In another EMG study undertaken at the US Air Force Academy (Tebbs, Eggleston, Prather, Simondi, & Jarboe, 1974), cadets who had received EMG feedback training scored higher on a check flight in a T-41 trainer, as rated by instructors on a variety of specific measures in a double-blind design. No similar effects were found, however, in an earlier flight simulator test. Unfortunately, there are no data as to whether the EMG-trained cadets used their relaxation during the check ride. Training had taken place several months earlier, and there were neither instructions to use it during the check ride nor instrumentation to monitor EMG levels.

This summary of studies relating EMG and performance offers little promise for the use of biofeedback-controlled muscular relaxation to achieve performance enhancement in stressful situations. Furthermore, it may be naive to search for acute situational benefits from EMG regulation; certainly muscle relaxation under stress would be maladaptive in many situations requiring sudden and vigorous physical response. The more chronic and general tension-reducing effect frequently described by those who employ a regime of relaxation training may, if real, result in increased ability to handle life stress. The aims of this program, however, did not include an evaluation of these claims.

4. Vasomotor Activity

It has long been known that human beings could control blood flow in peripheral vascular beds and that some people could alter skin temperature of the hand on the basis of vivid thermal imagery, hypnotic suggestion, or suggestion given in the waking state. The classical conditioning of peripheral blood flow also has a long history. What was new was in the work of Taub and his associates under this program (Taub, 1975) in the development of techniques that permit training the ability to consistently self-regulate sustained alterations in parameters associated with peripheral blood flow. All of these techniques are based upon the use of some form of augmented feedback.

Work in his laboratory was designed to enable subjects to produce both increases and decreases in hand skin temperature that could be learned rapidly and sustained over a reasonably long period of time. The method involved operant shaping of small variations in skin temperature by means of changes in a visual information display. Following a period of development, it was found that a large majority of the population could perform the task. After learning bidirectional control, some subjects routinely displayed changes of 8°-15°F in 15 min. Subjects were also found capable of retaining the response over a period of months, of maintaining a considerable increase in skin temperature over approximately three-quarters of an hour while performing a concurrent task, and of self-regulating temperature increases when subjected to different types of cold stress. All of these phenomena have clear practical implications.

The data indicated that there was a surprisingly large difference between experimenters in the ability to train subjects to self-regulate skin temperature. It was also found that when feedback was given from a single, punctate locus, subjects developed considerable anatomical precision of response as training progressed. In contrast, when temperature feedback was used in conjunction with autogenic phrases to promote relaxation, a temperature increase measured at one point on the hand probably represents not only a change in blood distribution over that particular area, but a response involving changes in many physiological parameters over the entire body. The two techniques may therefore involve entirely different mechanisms.

In recent years, a substantial number of investigators have been successful in training subjects to establish self-regulatory control over peripheral blood flow, using either temperature or plethysmographic feedback. The work of Roberts and co-workers (1974), Surwit and Shapiro (1974), and Friar and Beatty (in press) is of particular interest because of methodological rigor. Several investigators, starting with Sargent, Green, and co-workers (1973), have employed either self-induced increases in hand temperature or decreases in blood flow to some regions of the head as a means of reducing the incidence of migraine headache. Other workers have attempted to employ handwarming as a therapeutic approach to Raynaud's disease. At this time, the results are promising, but in neither case can the demonstration of efficacy be considered conclusive. Many other potential applications appear feasible, including the self-regulation of temperature increase in the extremities in cold environments. The feasibility of self-regulation of skin temperature during cold weather will be examined at the Naval Air Development Center in an applied study of the techniques developed under the ARPA Self-Regulation Program. Consequently, there will be a critical test of research findings in this area.

5. Conclusion

Several conclusions offer themselves as a result of this body of work. First, it seems that biofeedback offers much less powerful and robust self-control over certain internal physiological events than many researchers anticipated on the strength of early anecdotal evidence. Clearly, from the work which has taken place in many laboratories, it is extremely difficult, if not impossible, to train subjects to regulate nervous system events to a level contrary to the best interests of their own physiology. If a subject is resting comfortably, alert but relaxed, he is probably not going to be able to lower HR from 72 to 40, or raise it to 130 simply by deciding to do so. And these data offer no apparent reason why he should wish to do so, other than to please the experimenter. Effects have been, in general, obtainable only in physiologically appropriate directions; attempts to develop ability to respond autonomically contrary to spontaneous tendencies have met with very limited success.

So far, this research has failed to identify specific configurations of physiological events which have unique and reliable concomitance with specific performance or psychological states, and which can be controlled for the purpose of eliciting these behaviors. The path of psychophysiological research is strewn with the negative results of those who believed that specific physiological events are associated with specific behaviors. The general vs. the specific physiological determinants of emotional states and the role of cognition in the labeling of the visceral changes are still far from settled (see Schachter & Singer, 1962; Plutchik & Ax, 1967). The difficulty of delineating unique physiological responses associated with performance over several tasks and across subjects is clearly illustrated in the many reports which have stressed not only situational specificity but also individual response specificity of physiological response patterns (Sternbach, 1966).

Quite early in the ARPA program, emphasis shifted toward the use of self-regulation to control of the physiological changes brought about by stress and to aid in the maintenance of arousal or alertness. Implicit in the first goal was the belief that if the visceral responses to stress could be brought under control, then the feelings of panic, fear, fright, anger, etc., would be reduced. This approach was motivated largely by the many observations that perceived physiological response often interacts with and intensifies the psychological state. The results of stress studies in this program, however, cast doubt on the ability of a subject to utilize previously acquired operant skills to maintain basal or near basal physiological activity during the crisis periods. Sleep loss and fatigue reduced the ability to maintain self-regulated brain activity, fear of shock changed the subject's ability to modify HR, and hyperbaric stress, plus the performance tasks, made it difficult to achieve EMG relaxation. At the moment of truth, effective self-regulation may not be possible. In any event, the usefulness of biofeedback training for handling stress has not been convincingly demonstrated.

On the basis of the brain wave, heart rate, EMG, and vasomotor work reviewed above, it is clear that there is no easy and powerful key available in biofeedback for significant enhancement of performance. Reliable relations between internal events and performance have not been convincingly demonstrated in this series of studies. Certainly the results of this research program offer little support for the initial goal of using voluntary regulation of physiological events to enhance performance. The few interesting laboratory results on simple tests evaporated when more complex operational tests were performed outside the laboratory. Based upon these results, further effort toward the development of biofeedback techniques for performance enhancement does not appear reasonable. While biofeedback may offer a way to learn to relax more rapidly and perhaps more deeply, and may assist in the maintenance of desired arousal levels, further search for unique cause and effect relations between specific internal events and discrete performance components seems unwarranted.

B. Biocybernetics Technology and Behavior

The Biocybernetics Program presently supported by ARPA is intended to develop highly interactive, closely coupled man/machine interfaces for the extension and enhancement of human performance. One of the major goals is to provide the ability to control a computer by direct entry of nonverbal bioelectric signals. The result, ideally, will be a man-computer system so highly interactive, and so closely and rapidly responsive in such fine detail to the wishes and needs of the user, that it serves as an extension of the user's own capabilities.

To capitalize upon the highly successful experiences with the Self-Regulation Research Program, that contract was modified to include the Biocybernetics Research Program with the goal of integrating ARPA's substantive efforts in Biocybernetics under a single management insofar as this was possible. To accomplish this goal, subcontracts have been awarded to the following investigators:

Mr. Kurt Enslein	Genesee Computer Center, Rochester
Dr. Jack Beatty	University of California, Los Angeles
Dr. Stephen Grossberg	Boston University
Dr. David Cohen	Massachusetts Institute of Technology
Dr. Robert Chapman	University of Rochester
Dr. Jacques Vidal	University of California, Los Angeles
Dr. Charles Rebert	Stanford Research Institute

In contrast to the first portion of this report, this final portion will describe both work to be done as well as work that has been completed as of December 31, 1975.

Mr. Kurt Enslein: Mr. Enslein has re-examined a portion of Dr. Larry Pinneo's (Stanford Research Institute) data, collected under another ARPA contract, to determine whether more sophisticated mathematical techniques could improve the percentage of accurate computer recognition of covert speech trials from 8 channels of EEG data. The words were: Right, Left, Up, Down, Near, Far, and Stop. The first work with these data showed that there were substantial difficulties due to the fact that identification data had been mixed with what were supposed to be signals. After clearing up this problem, Mr. Enslein performed clustering on the data from one session (Session 2) consisting of 11 trials on each of the seven words. From this experiment, two major clusters emerged. These were associated in one group with the words Up, Near, and Right, and the other four words in the other cluster. Upon attempting to reproduce these results with other sessions, a great deal of difficulty was encountered. From an examination of the signals, it was felt that the problem might reside in the fact that the time reference for the different trials was inadequately specified. Thus in the next phase of the experiments, Mr. Enslein time-justified the signals on one pair of electrodes by means of serial cross-correlation, then used the same lags or leads and applied them to the signals of other electrodes. After smoothing the signals via the Tukey 53H technique, he then performed a stepwise discriminant analysis for four words. This result, in turn, led him to try three words since one word seemed to be particularly causing most of the misclassification. The results indicated that the time justification of signals did not seem to carry across sessions. In other words, there were substantial undefined differences in the experimental conditions between sessions such that the classification functions derived in one session were not reproduced in another session.

Mr. Enslein pointed out that the experiments he had performed with the Pinneo data were by no means exhaustive. Other time-justification algorithms are possible and other classification logics also exist. He, however, felt at this point that the goal of identifying concepts with signals may well still be possible but that undefined changes in the experimental conditions or other considerations have caused a variation in the signals to be introduced from session to session.

In addition to analysis of the Pinneo data, Mr. Enslein has applied mathematic clustering techniques to evoked response data provided by Dr. Emanuel Donchin. In a follow-up of encouraging pilot study results, data from 11 additional subjects were examined. Recordings were obtained from EEG electrodes 3 and 4, the electromyogram signal, and a dynamometer signal which represents the output task that the subject performed. In this experiment the subject was told to squeeze a dynamometer, and one looks back in time from the early rise of the dynamometer signal to the EEG signal which preceded the event. The questions asked in the clustering experiment were whether (1) clusters of EEG could be found, and (2) whether these clusters could be related to some characteristics, particularly amplitude and rise time, of the dynamometer signal. Thirteen clusters were found, and certain conclusions were possible:

(1) Distinct clusters are found.

(2) The clusters are subject- and condition-independent.

(3) There appears to be a relationship between the cluster identities and the range of the dynamometer signal, i.e., the force used by the subjects.

It May well be that the investigator will find other relationships in these data beyond those enumerated above. Much further detail is available in the complete computer outputs, which are available as needed.

Dr. Jack Beatty: Dr. Beatty has begun a series of experiments exploring the utility of pupillometric measurement for the estimation of momentary information-processing load or mental effort associated with various functions and tasks. The objective of such a program is to provide a basis for computer identification of momentary shifts in cognitive function for use in closely coupled man-machine systems, such as computer-aided instruction (CAI) systems, or vigilance-monitoring devices.

In an initial study, 5 university students served as volunteer subjects whose tasks were to detect the presence of a 100 msec, 1 KHz sinusoid against a background of 2.6 KHz white noise. Each of the 64 trials of an experimental session was of 5.1 sec duration during which pupillary diameter was continuously recorded. Momentary pupillary diameter was measured using a Whittaker Series 1000 TY Pupillometer.

The evoked pupillary response was segmented into three separate periods for analysis purposes: pre-warning period, warning-to-signal period, and the period between the signal presentation window and the delivery of the response cue. In the pre-warning period, mean pupillary diameter failed to differentiate the experimental conditions, either with respect to the correctness of the response, the confidence of the response, or ordering of conditions by inferred value of the internal stimulus representation, as indicated by signal-detection theory.

Similarly, the pattern of pupillary response in the 2-sec period between the delivery of the warning signal and the window in which the sinusoidal signal might appear, does not appear to vary systematically as a function of experimental conditions. An analysis of variance performed on the averaged dilation following the warning signal was also not significant.

Patterns of pupillary response in the post-stimulus period, however, reflect not only generalized aspects of the experimental task, but also specific processing of sensory information leading to decision. It is in this period, after the potential delivery of sensory information and before the initiation of an overt behavioral response, that the pattern of pupillary dilation varies as a function of response category and reflects the covert processing of sensory information. The peak pupillary dilation in the first second following the stimulus window pupillary dilation behaves in much the same manner as that previously reported for P300 as a function of response category.

An analysis of variance computed upon the mean pupillary diameter in the 1 sec following the stimulus window confirms this observation. The effect of response category is highly significant across the four categories. The magnitude of the post-stimulus pupillary dilation to correctly detected signals appears to vary as a function of decision confidence, as does the P300 wave of the cortical evoked response.

Dr. Beatty believes his finding that a distinct short-latency pupillary dilation may be observed following the detection of a weak acoustic signal and that the amplitude of the dilation increases with increasing certainty of judgment suggests the following: First, pupillometric measurement techniques might be useful in determining the outcome of a covert cognitive process in the absence of an overt behavioral indication of that outcome. In certain circumstances, momentary pupillary diameter might serve as a physiological data source in a closely coupled man/machine system.

Second, the fidelity of the mapping between detection certainty and pupillary dilation provides further evidence of the sensitivity of pupillary movements to cognitive events.

Third, the fact that the pupillary response and P300 are similar in both latency and their relationships between amplitude and certainty suggests that both might reflect aspects of a common neuropsychological process.

Dr. Stephen Grossberg: The Foundation is also supporting a preliminary study by Dr. Grossberg to investigate the feasibility of the concept of "remote principal investigator" through use of the ARPANET. In this instance, Dr. Grossberg is actively directing research, via the ARPANET, in Dr. Donchin's laboratory at the University of Illinois. Dr. Donchin is also a participant in the Biocybernetics Program, under a separate contract.

Dr. Grossberg has met with Dr. Donchin's group and they have planned a series of experiments on human information processing, using the P300 component of the evoked response as a process indicator. The goal of this study is to understand how people pay attention to fluctuating combinations of cues that vary in their information content.

Dr. Grossberg has also conducted a series of seminars to help Dr. Donchin's staff better understand past models of sequential data processing by humans and to help them to design models of this phenomenon. Dr. Grossberg is also actively at work on modeling mechanisms that are of central importance to the goals of the Biocybernetics Program.

Dr. David Cohen: Dr. Cohen's work at the Massachusetts Institute of Technology is focused on the fact that the electrical currents generated by the brain produce a magnetic field around the head. It has been demonstrated that this field, although very weak, is measurable in a magnetically shielded room with a superconducting magnetic detector; a recording of the brain's magnetic field is called a magnetoencephalogram. In order to help bring magnetoencephalography from the initial stage of feasibility to the stage where scientists can use and exploit this new technique, Dr. Cohen is involved in two projects. The first project is the development of a prototype detector having high reliability and a greater sensitivity than those which are now commercially available. A contract for development of this equipment has been given to a San Diego firm. The second project is the analysis and publication of MEG data recorded from the normal brain during various states, and also from abnormal brains. The raw MEG data for this analysis and publication have, in large part, already been recorded. The preparation and publication of these data will allow their use by the scientific community. Both projects are to be performed concurrently in a 1-year period. This project is well underway, and meetings with EEG consultants have been held to aid in interpretation of the MEG data.

Dr. Robert Chapman: Dr. Chapman is focusing his studies on the possibility of obtaining semantic meanings of words from brain waves. One of the major goals of the Biocybernetics Program has been to allow computer inference of specific mental commands, for enhanced command and control. The aim is to relate bio-electrical events to the internal meanings of language, rather than to any particular pattern of stimulation (e.g., written or spoken words of a particular language) which elicits particular meanings, or to any particular pattern of response (e.g., speech) which expresses particular meanings. It is the internal semantic meanings which are to be identified via bioelectrical potentials.

In the first phase, previously completed and reported, internal semantic meaning was manipulated by carefully selecting stimulus words. In the phase now underway, the internal semantic meaning is further manipulated by eliciting semantic judgments along selected scales. For this purpose, the subject's task is the semantic-differential task, as used by Osgood in developing his semantic analysis. The semantic-differential task requires giving each word a semantic-differential rating on a designated scale. Fifteen scales were used, five that were heavily loaded on each of the three Osgood dimensions. Since only one scale at a time was used, the semantic dimension on which it is heavily loaded will be more activated than the other two dimensions. Thus, a 6 X 3 factorial design is being used: six semantic categories of words (representing high and low ends of the Evaluation (E), Potency (P), and Activity (A) dimensions) combined with three kinds of semantic-differential tasks (representing the task activation of the E, P, and A dimensions). This permits assessing the main effect of the semantic meaning evoked by the words, the main effect of the semantic meaning induced by the semantic-differential task, and their interaction. It is hypothesized that when both the stimulus word and the task scale activate the same semantic dimension, the neural processes underlying that semantic process will be maximized and its expression in the EPs enhanced.

Progress to date has consisted of collection of evoked potential data and the computing of averaged evoked potentials from these data. Portions of the data collected so far have been edited, codified, formatted, punched on cards, and read onto a disk storage file, awaiting the addition of further data. The progress in this time-consuming data collection, preliminary computation, and preparation phase is appropriate to completion of the project on schedule.

Dr. Jacques Vidal: The work of Dr. Vidal focuses directly upon biocybernetic control in man-machine interaction. His work can be divided into four categories. The goals for these categories will be presented below. The progress that has been made toward achieving these goals is difficult to determine at this time, as only a brief progress report has been submitted.

(1) Continuation of laboratory experiment program aimed at the closed loop identification of evoked responses in real time. The original experimental program (described in earlier proposals and conceived of for a 3- to 5-year span) is being followed. As acceptable discrimination has been obtained with sensory input, the focus will now be moved toward the integration of cognitive components; or, in other words, to search for discriminable evoked response from identical physical stimuli when the stimulus meaning is changed in the context of the experiment from trial to trial. Evidence has come from several quarters that distinctive signatures are induced in the evoked response, but it has not been shown whether these can be identified in real time with single data epoch. Experiments that are now in various stages of completion are:

a. A demonstration experiment involving the running, via subject's EEG, of a computer-generated maze. Selection of moves will be made by directing gaze (although the computer will infer from brain waves only) and thus visually acquiring a selected target on the screen. This procedure is analogous to the use of a light-pen to select subroutines from a list on a graphic computer terminal. This will be the first experiment involving the actual closing of the feedback loop and attendant operant conditioning in the evoked responses.

b. Continuation of research on fast components using pattern stimuli, contingent on the results of initial phase.

c. A first attempt at using human aces as stimuli for evoked responses. A graphic program with outside control of face parameters has been produced.

(2) Continued investigation of specialized computer methodology for on-line real-time EEG identification. Current work by Dr. Vidal emphasizes the importance of preprocessing and of special-purpose featuring. The base work has revolved around the use of stepwise discriminant analysis now being combined with factor analysis as a prior step. This replaces raw samples by weighted sums prescribed by factor loadings and accomplishes data reduction regardless of the physiological meaning (or the absence of) for the factors. This approach is providing a measure of the effectiveness of the preprocessing steps, identifies the time windows that contain the information in the evoked responses, and generally provides a protocol and a performance index to evaluate each method and chart future progress.

Preprocessing (special-purpose filtering), discriminant and factor analyses have now been incorporated as a part of the Brain Computer Interface computer software system and are performed exclusively using in-house laboratory resources.

(3) Finalization of the computer configuration (especially software) in the Brain Computer Interface Laboratory. The system is being documented as a breadboard and demonstration model for the principles involved in a man-machine loop incorporating evoked response information. A set of demonstration experiments is being produced for that purpose. The experience gained with the system at each level of operation (data acquisition, processing, file management and results documentation) will be an invaluable source for structuring further computer-based research involving real-time biological signals.

(4) Planning for future hardware package. Dr. Vidal is engaged in determining the outline and possible architecture for a miniaturized, self-contained microprocessor system that could be used in practical applications. There are no plans at this time to actually build a prototype, but rather to investigate

feasibility and to outline a tentative structure that would be realizable within the state of the art as a first evaluation of the trade-offs, in terms of size, cost, and flexibility.

The UCLA biocybernetics group is reporting complete operational success in the first phase of its objective; namely, the correct recognition and classification of stimulus identity in a small alphabet of possible stimuli in each single epoch of EEG visual evoked response. Stimuli used have been flashes either patternless in a set of colors or patterned in one color. Because of the clear differences in codes, patterns and colors are expected to be identifiable separately or in combination, but no experiments with combinations have been attempted yet. Expected accuracy with random subjects, based upon the studies on single stimuli, is about 80%. The best subjects operate consistently over 95%. This level of performance has been obtained by submitting each epoch to a sequence of processing steps which include, in chronological order, (1) a priori artefact rejection; (2) Wiener filtering; (3) stepwise selection of best samples; (4) recursive outlier rejection; and (5) real-time defaulting.

In summary, Dr. Vidal reports that very consistent peak histograms are found in specific conditions. Consistency, however, is very much dependent of stimulus dimension. For instance, red flashes in absence of contour produce large sharp peaks at 80 msec with incredible sharpness which allow identification of red flashes from other colors with almost certainty in each response. Thus, the front-wave arrival of red-pigment responses on the occipital cortex can be assessed with a precision of the order of 1 msec. More litter is observed with green light and still again with blue. A second significant phenomenon was the discovery of peak consistencies at times that did not correspond to a maximum on the average but rather were located on the flank of a major average component. Peaks and dips would somewhat average out, but the regular occurrence of the events at stable times suggested the presence of neural happenings serving distinctive signatures but occurring only some of the time replications of the stimulus. Their meaning would have to be assessed separately. Dr. Vidal's recommendations from the study were:

(1) Peak occurrences, at specific times in the 40-160 msec window, should be included in the decision rule.

(2) A time varying digital filter should be introduced on-line with initial bandpass characteristics of 3-300 Hz that would be progressively degraded to a low-pass of .1-10 Hz for the end of the response, i.e., after 160 msec approximately.

Dr. Charles S. Rebert: The purpose of the studies by Dr. Rebert are to confirm and expand on preliminary findings indicating that performance in a target-detection task is a function of EEG asymmetry; to discover the cortical locus primarily involved in the EEG performance relationship; to evaluate the EEG parameters that best reflect EEG asymmetry; to study asymmetry of slow potential components of the EEG; and to investigate the feasibility of influencing human performance by presenting stimuli contingent upon the momentary state of EEG asymmetry.

An experimental paradigm has been developed by Dr. Rebert that would lead presumably to differential engagement of right and left hemispheres in human subjects. This design would also allow analysis of target-detection performance, reaction time, EEG power spectrums, and visually evoked potentials to target and nontarget words and pattern stimuli. Dr. Rebert summarizes his results to date, as follows:

a. EEG asymmetry and target recognition. Eight subjects, screened for handedness and normal EEGs, were tested in verbal or pattern target recognition. Right-hemisphere alpha was augmented in the spatial task contrary to expectations, but when the hemisphere appropriate to a stimulus category (verbal or spatial) was most aroused, as indicated by EEG asymmetry, reaction time to the stimulus was fastest; e.g., reaction time to words was fastest when the left hemisphere was most aroused relative to the right.

Evoked potentials to words were indistinct but were clear in response to patterns. The major component of the spatial EP to target stimuli was larger in the right than in the left hemisphere in 7 of the 8 subjects.

b. On-line trigger of stimuli by EEG asymmetry. Because alpha activity apparently reflects cortical "idling," it was predicted that triggering a word stimulus with a relatively larger left-hemisphere alpha burst would result in slower reaction times to words than when they were triggered by right-hemisphere alpha increments. Results in 11 subjects were that 4 behaved as predicted, 5 behaved opposite the prediction, and 2 showed no consistent verbal-spatial relationship. Thus, in 9 of 11 subjects the hemisphere responding most efficiently to patterns was opposite that responding most efficiently to words.

c. Volitional trigger of words and patterns: Biofeedback. Observations were made in 1 subject under conditions where right-hemisphere alpha activity always triggered words and left-hemisphere alpha triggered patterns. The subject learned rather easily to increase the production of words; i.e., to augment the normal high incidence of right-hemisphere alpha, but only with difficulty was she able to increase relative left-hemisphere alpha and reduce it in the right hemisphere.

d. On-line trigger of mixed words and patterns: Pattern difficulty. Computer program modifications were completed for evaluating an on-line paradigm where either left or right alpha increments triggered words or patterns in random order. Preliminary runs with 2 subjects suggested that pattern difficulty might be an important parameter influencing EEG-performance relationships. Six additional subjects were screened for handedness and 4 were tested in this paradigm with variation of pattern difficulty. The data were generally unsatisfactory because of the lack of alpha in two cases and excessive eye blinks and muscle artifacts in the other two. It did not seem reasonable to pursue this exact methodology further because of the technical difficulties. Mixing the verbal and nonverbal tasks seems to induce excessive stress and consequent artifacts.

e. Asymmetry of slow potential expectancy waves. It was hypothesized that asymmetries of contingent negative variations (CNVs) might be related to hemispheric cognitive differences and might be related more closely to discriminative performance and reaction time than the vertex wave. Cognitive sets are being induced in an ongoing study by using as the warning stimulus either words or patterns, and as imperative stimuli either antonyms or synonyms of the words, or the same or different patterns. Subjects are required to make differential motor responses to imperative stimuli that are the same or different than the warning stimulus. Parietal, frontal, and vertex placements are being studied.

In parietal leads, CNVs tended to be larger in the left hemisphere preceding words and larger on the right preceding patterns, but the Task X Hemisphere interaction was not statistically significant.

Dr. Rebert has studied in depth one subject with possible reversed dominance. Though the results are not definitive, he believes his findings suggest that the pattern of EP distribution between the hemispheres might be a very sensitive index of cerebral dominance.

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