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Alpha enhancement the effect of feedback modality in an EEG biofeedback paradigm

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ALPHA ENHANCEMENT: THE EFFECT OF FEEDBACK MODALITY
IN AN EEG BIOFEEDBACK PARADIGM

A Thesis
Presented to the
Faculty of
California State College,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Psychology

by
Lucien T. Thompson III
June 1983
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Approved by:
ABSTRACT

Reviews of the EEG biofeedback literature indicate no substantive rationale for restriction of feedback modality to only auditory and visual feedback channels. Reports for other response systems indicate that tactile feedback (in the form of vibrotactile stimulation of the preferred hand) produces different response magnitudes than do other feedback modalities, as well as different rates of learning. Early reports of unconditioned alpha enhancement indicated that stimulation in the tactile modality produced superior enhancement compared to both auditory and visual stimuli. The present study, using a between groups design, was the first to test the relative effectiveness of tactile, auditory, and visual feedback presentation within a biofeedback paradigm for the enhancement of EEG alpha power. Since most biofeedback theories contend that a contingent relationship between feedback and response is required in order for significant performance changes to occur, both contingent and noncontingent feedback was given within each of the three modalities tested. The results of this study indicate that integrated EEG alpha power for both left and right brain hemispheres was enhanced significantly more using tactile feedback than using the other feedback modalities, with contingent feedback subjects demonstrating the most significant enhancement. Visual feedback tended to suppress alpha power during feedback presentation, with contingent feedback subjects showing the greatest suppression. Contingent auditory feedback presentation
eventually led to alpha enhancement during later feedback periods, while noncontingent auditory feedback presentation did not. Interestingly, only the contingent tactile group's enhancement persisted through the non-feedback postbaseline period recorded within the biofeedback sessions. The results are discussed in terms of an operant conditioning model of alpha biofeedback, taking into consideration the nature of the alpha response and the specific stimulus parameters required for optimal performance of the response.
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Most of all, I gratefully acknowledge the outstanding assistance given me by the woman whose company and conversation I cherish most, my friend and wife, Rosa. Without your encouragement, I never even would have tried. Thank you.
Presently, nearly all clinical and experimental applications of biofeedback (BFB) employ either auditory or visual forms of feedback (FB) (Schandler & Grings, 1978). The tactile, gustatory and olfactory senses are generally excluded as FB channels. An examination of the BFB literature shows no empirical rationale for restricting FB to only two sensory modalities. In fact, tactile FB delivery systems have been developed. Although auditory and visual stimuli have both been shown to suppress EEG alpha production, alpha enhancement BFB training has relied exclusively upon auditory and visual FB, with mixed results. The relative effectiveness of tactile FB presentation is compared with that of auditory and visual FB presentation for alpha enhancement in the present study, using a typical BFB paradigm for illustrative purposes.

**Theoretical aspects of BFB**

Blanchard and Epstein (1978, p. 3) defined and illustrated BFB as the processes of the detection and amplification of a physiological response, conversion of the response to an easily processed "auditory or visual signal," and feedback of this signal to the subject whose task it is to change (or stabilize) the response. The role performed by FB in the modification of psychophysiological responses has been disputed (Hatch & Gatchel, 1981). Is the FB an information source, a conditioned stimulus, or a reinforcer? Black, Cott, and Pavlovski (1977) argued that our understanding of isolated response systems is too rudimentary to permit general statements to be made regarding the function of the feedback in BFB. They note that investigators should precisely define the parameters of the manipulations they made, from
which their conclusions were consequently drawn. Although overgeneralization beyond the available data should be avoided, most investigators of BFB phenomena prefer to explain their results in terms of their own theoretical orientation. Unfortunately, no extant theory completely accounts for all of the existing data, nor for the success or failure of various techniques.

Gaarder (1979) conceptualized BFB in terms of cybernetic information theory, wherein a system is controlled by feedback of information about the state of the system to the operator or control mechanism. In such a model, FB serves as additional information to that usually available for homeostatic regulation. Schwartz (1979) similarly saw BFB from the viewpoint of general systems theory. In that theoretical analysis, available information may be too attenuated to permit normal "negative feedback loops" to operate, resulting in "disregulation". FB augments or makes perceptible the available information, closing the loop and eliminating "the disease" or nonstasis of the system. These constructs, however, fail to account for phenomena such as single motor unit conditioning (Basmajian, 1963), an artificially segregated response, which has no relation to normal homeostatic mechanisms. In such cases, BFB in effect creates whole new FB loops for bodily regulation.

Methodologically as well as theoretically, the "information" or signal is distinguished from "noise" or noninformational activity within a system. The improvement of the signal-to-noise ratio (Schwartz, 1979) is a prime consideration in designing a BFB system, at all stages of
the loop from signal detection through signal transduction to signal transmission back to the nervous system.

Cognitive theorists interpret FB as an information source which enters conscious awareness. Meichenbaum (1976) outlined the following steps in his cognitive formulation of BFB: (a) initial cognitive awareness of the system or response, which is monitored to provide information about its state; (b) cognitive integration of this information leading to volitional cognitive changes, skills-acquisition, and rehearsal of the new skill; and (c) generalization of the response (perhaps with eventual automaticity of the response) and transfer of the new cognitive skill to other settings. Chatterjee and Eriksen (1962) noted that cognitive expectancies of success or failure produced directional effects in response magnitude, in the direction of expectation, within sessions of autonomic conditioning. The role of expectancy in BFB is frequently allowed for in experimental designs, with a "free feedback" period provided (Yates, 1980, pp. 414-469) to allow for normalization of the response.

The use of imagery and the importance of the emotional involvement of individual patients in clinical applications of BFB techniques was stressed, but not fully explained, by Schwartz (1975). Imagery rarely remains constant from moment to moment or between individuals, yet reliable patterns of control of multiple responses are seen throughout the BFB literature.

Singer (1976) viewed BFB as an example of the self mastery of the psyche, explaining the process in Jungian psychoanalytic terms,
including "the union of intuition with technology". Other cognitive models of BFB have also been formulated, some combining features of those outlined here. The major difficulties with cognitive models of BFB revolve around the inherent problems of the definition and measurement of covert cognitive events. While electrochemical changes can be reliably discerned, cognitive events are necessarily subjective. Events which cannot be quantified and whose necessary conditions cannot be stipulated have a low probability of being accurately reproduced (see Eddington, 1929). The need to produce replicable results, upon which the scientific analysis of behavior is based (see Skinner, 1959), has led most BFB researchers to adopt more parsimonious conditioning models, both for development of methods and interpretation of results. Unfortunately, the prediction of BFB outcomes using traditional classical and operant conditioning models is also fallible.

Furedy and Poulos (1976) formulated and tested a classical conditioning model of BFB training, with the FB serving as a conditioned stimulus which comes to be associated, over a number of trials, with the organismal state (the unconditioned stimulus) which produces directed changes in specific physiological responses. Presentation of the FB then elicits the response (which has become a conditioned response) in the absence of the unconditioned organismic state. Dawson and Furedy (1976) further postulated a necessary-gate hypothesis, in which awareness of the FB-state relationship is a necessary but not sufficient condition for successful control of the response. To some degree, this approximates Meichenbaum's (1976)
cognitive conceptualization. This model presents problems in the
operationalization of its variables, particularly 'awareness'. Also,
the response is rarely if ever generated without concurrent presence
of the original unconditioned state leading to the response. This led
Furedy (1979) to further modify his model, attempting to demonstrate the
necessity of classical conditioning as a first step in the acquisition
of operant control of physiological responses. However, no variation
in the responses Furedy selected occurred during the initial
Pavlovian conditioning phase of training, so it is largely conjectural
to assume that the small superiority of response magnitudes demonstrated
by pretrained subjects compared to naive subjects was a result of
classical conditioning. More likely, the differences were a result
of increased familiarity with the task gained during pretraining.

Failures of other theories to mesh with observed performance within
FB sessions have led the bulk of BFB researchers to adopt simple operant
conditioning paradigms for explanatory purposes. The conception of
FB as a reinforcer has been valuable, although for some individuals,
and for isolated response systems, it cannot be reliably demonstrated.
As noted earlier, no single current model accounts for all of the
available data. Operant models, however, do allow for elegant tests
of their underlying assumptions, and therefore increase the scope
of the conclusions obtained through their use.

Grings (1977) has discussed the limitations of models such as
orientation, conditioning, and learning in BFB. Models must inherently
distinguish and separate one process from another, although in
reality the distinction may not exist. The primary advantage in the application, however, of such models to BFB training is their ability to produce predictions amenable to testing. Operant models of self-regulation are used widely within the BFB literature.

Early work in the conditioning of autonomically mediated responses was conducted from the 1930's until the early 1960's. Discussions of its shortcomings are provided by Katkin and Murray (1968; Katkin, Murray, & Lachman, 1969). Kamiya (1968) proposed a tenative operant conditioning model to account for learned control of brain waves. The work of Miller (1969) with curarized rats, however, is usually cited as a pioneering entry in the operant BFB literature. Miller demonstrated the functional autonomy of various physiological response systems governed by the autonomic nervous system. In his model, FB serves as a reinforcer for a response which the organism normally has in its behavioral repertoire. FB served to increase the frequency and/or magnitude of responses. Counterbalanced trials also demonstrated facility in reducing the operant level of performance. The FB operated successfully in discrimination tasks, with the rats performing various responses dependent upon the external conditions presented. Miller also succeeded in demonstrating escape and avoidance responses, with the removal of aversive stimulation serving as the reinforcer for autonomic performances. Although attempts at replication of these early studies with curarized rats have been fraught with technical problems and a general lack of success (Dworkin & Miller, 1977), the interest which Miller's work created in BFB has led to the
development of operant techniques for the self-regulation of biological responses for human subjects which have had numerous successes (see reviews in Fischer-Williams, Nigl, & Sovine, 1981, for example).

Hefferline, Keenan, and Harford (1959) demonstrated that human subjects could successfully perform escape and avoidance responses (extremely small finger twitches) without their 'awareness' of the response being performed or the contingency involved. Numerous other examples of operant or instrumental conditioning paradigms used in BFB (e.g. Brener & Kleinman, 1970; Hatch, 1980; McCanne & Sandman, 1975) have demonstrated significant changes in psychophysiological systems without recourse to unmeasurable volitional explanations.

Yates (1980) repeatedly raised the issue that commonly used FBs lack any natural relationship with the primary reinforcers of the responses being conditioned, and noted that rigorous comparisons of the informational vs. the reinforcing qualities of FB are difficult to design and thus rarely conducted. The operational assumptions defining the role of FB are thus to a large degree untested. Resolution of such problems are necessary to the integrity of operant models of BFB.

Another problem plaguing operant BFB theorists is the failure of the paradigm to produce reliable control of some response systems. For example, Shapiro and Surwit (1979) questioned whether heart rate deceleration is possible through BFB. The applicability of the operant model to a number of responses is less than optimal. Thus, the reality of the effects of BFB has been questioned, with some writers instead favoring placebo explanations (Yates, 1980, pp. 286-324). The
simplicity of operant conditioning models, however, has been of value in BFB, allowing for precise measurement and accurate testing of empirical assumptions. Although some degree of uncertainty is inevitable in any model of reality (Davies, 1980), these models strive via controlled manipulation of variables to reduce uncertainty to acceptable levels. The applications of operant paradigms for BFB training will be discussed further throughout this paper.

Applications of BFB theory

Theoretical explanations and empirical explication of the processes involved in BFB have not been able to keep pace with the flood of applications BFB technology has found in the treatment of clinical symptoms (e.g. Olton & Noonberg, 1980; Yates, 1980). As a tool, BFB has been used in the treatment of cardiovascular disorders, sexual dysfunctions, seizure and sensory problems, muscle tonus control, and numerous autonomically mediated disorders including asthma, migraine headache, and incontinence (Miller, 1978). The degree of success in clinical application has varied widely.

Blanchard and Young (1974) reported that only in muscle retraining, elimination of subvocal speech in reading, and elimination of tension headaches did empirical evidence support the efficacy of BFB treatment. They also found encouraging but methodologically flawed evidence of effectiveness in eliminating cardiac arrhythmias, lowering blood pressure, and reducing the frequency of epileptic seizures. Shapiro, Mainardi, and Surwit (1977) cautioned against predicting a high percentage of successful treatment outcomes, and indicated that other
modes of therapy such as relaxation training may be equally effective in the treatment of many diseases. Miller and Dworkin (1977) stressed the need for further research and understanding of the basic processes involved in clinical improvement, and discussed problems in the use of BFB, including placebo effects and the inevitable variation in the therapeutic character of treatment by different practitioners. Olton and Noonberg (1980), in their review of the clinical BFB literature, pointed out numerous methodological flaws in studies of BFB's effectiveness, and the apparent parity of BFB successes with that of other forms of treatment for many clinical illnesses. Why are the techniques of BFB, so effective in the laboratory, frequently ineffective in practical applications? Is the problem with the technique, or with its application?

Price and Gatchel (1979) suggested that one of the reasons for the disarray in the clinical BFB literature and for the large number of subjects obtaining negative results may be the variables introduced by individual differences. They suggested tailoring the treatment to the individual patient so as to improve outcomes. Alternately, it has been postulated (Tursky, 1979; Yates, 1980, pp. 104-218) that the auditory and visual signals traditionally used for FB are remote from and out of phase with the internal "closed feedback loops" which normally control bodily functions. Low rates of success in conditioning could thus be attributed to a lack of effective response consequences. In some cases, an organism may even be contraprepared to associate certain reinforcers with particular responses (Seligman, 1970).
Transfer of training using traditional auditory and visual FB cues which are not available outside of the BFB clinic is often poor (Price & Gatchel, 1979). Researchers have attempted to determine the specific conditions necessary in BFB for transfer to occur. Unfortunately, the primary emphasis in the research literature has revolved around FB parameters within one or two sensory modalities, rather than across modalities. Why is this the case?

Investigation of traditional variables in BFB

Yates (1981, pp. 11-49) commented that BFB training has different effects on different individuals. Some are relatively successful at learning the targeted behaviors. Others are failures. Each session of biofeedback can be considered to consist of a large, but finite, number of performance trials with immediate reinforcement of correct responses. Successful subjects, over the course of a varying number of trials, improve their performance (as compared to baseline levels) before tapering off at some higher asymptotic level. Unsuccessful subjects, who tend to become discouraged and drop out of lengthy training programs, fail to improve their performance. A number of variables have been implicated in this pattern of success and failure, including transitory placebo effects, FB contingency, schedules of FB presentation, the action of instructional variants, and the type of FB used. FB modality, however, is seldom considered.

The hypothesis that BFB effects are solely a result of the placebo action of a new form of treatment has been repeatedly tested and found lacking. Travis, Kondo, and Knott (1974a) tested
the effect of varying FB's contingent relationship to EEG alpha enhancement. Comparing contingent, noncontingent control, and yoked-control groups, they found that contingent FB produced significantly greater alpha enhancement than did the other conditions. Contingent FB subjects acquired the response rapidly, and reached 80 percent of asymptote within 20 minutes. Prior to training, no differences in alpha production existed between groups.

Klinge (1972), in a study of galvanic skin response, reported that FB which was accurately related to changes in response was more effective for control than placebo FB which falsely indicated correct responses. Placebo FB, however, was more effective than false negative FB or non-FB control conditions. Rupert and Holmes (1978) reported that multiple sessions of BFB did not significantly increase the amount of heart rate control achieved during the first BFB session. They also found that contingent FB in combination with accurate instructions about the desired change in response produced significantly better results than did instructed placebo feedback or verbal instructions alone. It can be concluded that contingent feedback should be coupled with accurate instructions regarding the relation of the FB signal to the task to produce the most effective control of responses in BFB. For some tasks, single short-duration sessions offer sufficient training for demonstrable learning of self-regulation.

Black et al. (1977) argued that other variables, including the schedule of reinforcement used in the delivery of FB, should be governed by the nature of the response and of the FB signal.
Gatchel (1974) tested the effects of continuous and fixed ratio schedules of FB presentation on learning of heart rate control. For heart rate speeding, continuous reinforcement produced the greatest magnitude of effect. For deceleration, no differences were noted between schedules, with the magnitude of the response in this case so slight that conditioning apparently had not taken place. The delay between the response and onset of FB can vary even within model lines of FB equipment available from manufacturers. The necessity for short delay of reinforcement, an assumption of traditional learning models, is diminished dependent upon the physiological system involved (Garcia & Rusiniak, 1977). Some responses, such as the EEG, are fast changing. Others, like contingent negative variation of the cortex and vascular pressure changes, occur slowly.

Generally, the FB in biofeedback applications takes one of two forms. Continuous (or analog) FB varies constantly as a function of the level of performance. Discrete (or binary) FB is turned on when a predetermined criterion level of performance is surpassed, and turned off when performance falls below criterion. Comparisons of relative successes utilizing analog or binary FB for galvanic skin response tasks (Klinge, 1972), heart rate speeding (Lang & Twentyman, 1974), and in enhancement of EEG alpha (Kuhlman & Klieger, 1975) revealed that analog forms of FB yield more reliable control of the responses than does binary FB. Olton and Noonberg (1980, pp. 14-17) theorized that the major reason for
analog FB's superior results is the increased information content of the FB signal as compared to a monotonous binary signal.

Lang and Twentyman (1974) emphasized that BFB results generalize only to certain responses. Different responses involving the same organ of the body may be modulated by totally different physiological mechanisms. Greenstadt, Schuman, and Shapiro (1978) demonstrated that the side of the body stimulated by FB (the FB laterality) frequently controls the magnitude and direction of a learned response. Thus, continuous FB interacts with other variables, altering its effectiveness in the control of targeted responses.

The role of instructions in BFB training sessions has been extensively tested. McGuigan (1973) emphasized that the conception of FB as a reinforcing stimulus is tenuously supported at best. However, the interaction of the FB signal with the signal's indications of success at achieving the goal of instructions may be the primary source of the reinforcing value of the FB. Bergman and Johnson (1972) tested this relationship, and found that the more specific the instructions were in defining the task and explaining the relationship between FB and the task, the greater the degree of control achieved. Neither FB nor instructions alone produced significant changes from baseline performance levels.

Similarly, London and Schwartz (1980) found that directional instructions combined with contingent FB were more effective in the control of heart rate than was the combination of FB with instructions
to merely attend to the response without attempting to control or vary it. Yoked-control subjects, however, whose FB was unrelated to their own performance, self-rated their control as highly as did true contingent FB subjects. London and Schwartz interpreted this finding to mean that both contingent FB and correct directional instructions are necessary for actual control of heart rate. 'Feelings' of control are insufficient.

Bouchard and Corson (1976) tested the hypothesis that positive performance information would produce superior performance when compared to negative performance information. In a between subjects design, those who received information indicative of correct responses performed better than those whose FB indicated incorrect responses. Apparently, appetitive consequences of the subject's behavior was more effective in achieving control than were negative consequences of behavior, in a heart rate BFB task.

Clearly, the combination of specific types of instructions with particular kinds of FB enables varying degrees of psychophysiological self-regulation, dependent upon the response and other conditions, by human subjects. The reasons for these differential effects are not clearly delineated within the BFB literature.

Tursky (1979) proposed that current FB strategies make use of unnatural (perhaps antagonistic) stimulus–response relationships. The role of instruction may well be to enhance the degree of associability of specific responses with nonsalient stimuli. Similarly, Lang and Twentyman (1976) demonstrated the effectiveness
of enhancing FB's reinforcing value by combining it with an external monetary reward. Stimulus variations unrelated to the response can alter performance in significant ways.

Tyson (1982) demonstrated that different stimuli within a single sensory modality have differential values as FB signals for alpha enhancement. Sawtooth auditory waveforms sound very different to the human ear when compared with sine waveforms. The degree of alpha enhancement achieved by subjects who received sine wave FB was significant. The alpha production of sawtooth FB subjects was similar to that of controls, who did not achieve alpha enhancement. Thus, the notion that some stimulus-response associations are more readily made than others, and that some stimuli serve more readily as reinforcers for particular tasks than others seems valid. This conception, and its role in BFB training, will be examined next.

Relevance of FB stimuli to the response

Garcia and Rusiniak (1977) stated that telereceptive (audio and visual) FB signals may interfere with rather than enhance performance in BFB tasks. Plotkin (1979) mirrors this view, stating that the initial task of a BFB subject is to overcome the inhibition of response frequently seen in the beginning of typical BFB sessions. Garcia and Rusiniak considered the vegetative nature of many of the responses modified in various BFB paradigms, and suggested that use of proprioceptive stimulation (for example, radiant heat fluctuation) might be more appropriate, particularly for applications where an increased arousal state
deters performance of the response. This series of suggestions was empirically based in part upon the work of Garcia and others in the study of biological constraints on learning, a relatively new development in the learning literature (e.g. Garcia, Hankins, & Rusiniak, 1974; Garcia, Kovner, & Green, 1970). A comprehensive review of the development of biological constraints concepts is beyond the scope (and intent) of this paper, but a synopsis of key points relevant to the present study is appropriate at this time in order to develop the concept of stimulus specificity.

Pavlov (1927, 1928) argued that any neutral stimulus could be arbitrarily selected for association with any unconditioned stimulus which produced a reflex response. The strength of the learned association, measurable in terms of the observed magnitude of the conditioned reflex, was dependent upon the number of trial pairings of the stimuli and upon the interstimulus interval, among other variables. Other early behavioral theorists (e.g. see Hull, 1943; Skinner, 1938; Thorndike, 1911) made similar assumptions concerning the parameters of instrumental and operant learning.

Rather than study a wide variety of responses, a limited repertoire was selected primarily for ease in measurement. Discriminative stimuli were arbitrarily selected. Food reinforcement for food deprived organisms was frequently chosen for the extremely pragmatic reason that hungry animals will work hard for food. Rather than study the entire spectrum of living organisms, it was assumed that the behavioral principles observed for any one
species applied to all. The behavior of the albino Norwegian rat became representative of all behavior (Beach, 1950). This general process view of learning led to many important discoveries about the control of behavior—although its basic premises are not empirically supported (Seligman, 1970).

According to the assumptions of the general process model, the observed phenomena of conditioned taste aversions should not occur. Yet they do: different stimuli have varying degrees of associability within and across species.

The assumption that frequency of CS-UCS pairing is necessary for learning to occur is true for a number of responses, but not for all. Instances of single trial pairings of tastes with illness resulting in powerful aversions have been demonstrated in a large number of species, including rats (Garcia & Koelling, 1966), quail (Wilcoxin, Dragoin, & Kral, 1971), guinea pigs (Braverman, 1974), and coyotes (Ellins, Thompson, & Swanson, 1983). Predatory animals have been shown to switch to alternate food sources and avoid selected prey, following a relatively small number of trial pairings of illness with baited carcasses of the familiar prey (Gustavson, Garcia, Hankins, & Rusiniak, 1974). Under certain conditions, the apparent salience of certain stimuli (particularly stimuli relevant to biological survival) is high enough that frequent pairings are not necessary for learning to occur. Thus, rapidity of learning is frequently related to the type of stimulus presented.
Another temporal factor once considered of prime importance in learning is the length of time intervening between presentation of the stimuli to be associated. A related assumption held that not only temporal, but also spatial contiguity of stimuli was required for the association to be made. However, taste aversions involving extremely long duration interstimulus intervals (e.g. Braverman, 1975; Revusky & Garcia, 1970) have been demonstrated in the laboratory. Associations between illness occurring in a familiar environment and ambient sensory cues present in a dissimilar environment have also been demonstrated (Nachman, 1970). These findings indicate that the relative temporal and spatial associability of various stimuli is different, depending upon their specific form and their impact on the physiology of an organism.

Contrary to Pavlov's assumption that the stimulus associated with a response could be arbitrarily selected, the evidence suggests that specificity of responses to particular stimuli is the norm (e.g. Capretta & Moore, 1970). Most animal species, for instance, associate taste cues with delayed organismic distress in the gastrointestinal system (Domjan & Wilson, 1972). Only a few readily associate exteroceptive cues in the feeding situation with the same interoceptive distress (e.g. Wilcoxin et al., 1971). Exteroceptive sensory cues have been shown to be more readily associated with noxious exteroceptive stimuli than with noxious interoceptive ones (Green, Bouzas, & Rachlin, 1972). The differences in conditioning success across species has in the past been related
to the instinctive behavior of different species in similar situations (Breland & Breland, 1961). It has been concluded that the biological makeup of specific organisms defines the operational limits of conditioning of different tasks (Garcia, McGowan, & Green, 1969; Rozin & Kalat, 1971).

Theorists conjecturing about the nature of BFB seldom mention the implications of studies such as those detailed above. Although methodological inquiries regarding the precise points of anatomy to be monitored for optimal signal responsivity are abundant, the rationale for conversion of this optimal signal into a FB stimulus in only two of the possible human sensory modalities is based pragmatically upon the simplicity of the conversion. The relevance of the class of stimulation to the response is apparently not considered (Garcia & Rusiniak, 1977; Yates, 1980, pp. 304-320). The final form which the information fed back takes is often arbitrarily selected. The simplicity and low cost of analog control of auditory and visual signal transduction has led to the manufacture of a wide variety of devices, of varying degrees of reliability (Olton & Noonberg, 1980, pp. 71-88). The continued assumption that the form of the FB stimulus is irrelevant to its content is open to empirical testing.

If, as the recent conditioning literature suggests, certain kinds of stimulation are better suited to performance of selected responses than are others, it follows that certain types of FB will produce better control in some BFB paradigms than in
others. As an illustrative example, the response of EEG alpha enhancement is appropriate for examination. The response has been examined under a great variety of conditions, its physiological antecedents are fairly well understood, and its susceptibility to control via current methods of BFB has been hotly debated within the BFB literature. A synopsis of the history of EEG biofeedback, and the relationship between alpha and sensory stimulation within different modalities, will serve in the formulation of the present study's design.

The EEG and BFB

In the late nineteenth century a Liverpudlian physician discovered evidence of electrical activity in the brains of rabbits and monkeys (Caton, 1875). Although the techniques of the time were crude, using hand-held galvanometers measuring direct current (DC), the activity of certain brain areas was soon demonstrated to be related to specific functional activities (Caton, 1877, 1887). Extensive work with animal subjects and rapid advances in the physical sciences eventually led to reports of minute alternating current (AC) signals from the intact human scalp (Berger, 1929, 1930). The precise source of these signals is still largely conjectural, although they are thought to be related to the collective extracellular potentials of whole populations of neurons in the cortex (Thompson, 1967, pp. 114-147). Berger termed his recordings of varying cortical potentials the electroencephalogram (literally, 'writing from the brain'), usually shortened to the EEG.
The EEG varies along two physical dimensions, frequency and amplitude, dependent upon the recording site and the functional state of the individual whose brain activity is being recorded. Berger (1930) reported two distinctive types of EEG activity: alpha waves and beta waves. Alpha was lower frequency (8-13 Hz) and higher amplitude (10-100 μV) synchronous activity predominating over the occipital and parietal cortex as recorded from the scalp, particularly when the subject's eyes were closed or when visual attention was unfocused. Beta, seen during periods of focused visual attention, was higher frequency (above 13 Hz) and lower amplitude (typically less than 10 μV) asynchronous activity. Berger hypothesized that the presence of beta activity in a particular area 'blocks' the production of alpha. This hypothesis was soon tested and experimentally confirmed (Adrian & Matthews, 1934). Two additional types of low frequency EEG rhythms were soon identified (respectively, theta, between 5-7 Hz; and delta, less than 5 Hz), with the general principle remaining that the lower the frequency of the brain wave the higher its amplitude.

Since the 1930s, the existence of functionally differentiated brain wave signals in localized areas has been proposed. Specific rhythms have been linked correlationally with many physiological and psychological events. Individual variation in the normal waking EEG is great, both within short sessions and across long periods of time (Engel, Romano, & Ferris, 1947; Hawkes & Prescott, 1973; Lynch, Paskewitz, & Orne, 1974a; Mulholland, 1972; Peper, 1972;
Van Dis, Corner, Dapper, Hanewald, & Kok, 1979). The basis for these individual differences has even been explained in terms of a genetic model of heritability of EEG variability (Vogel, 1970).

A wide variety of measures of the 'strength' of EEG responses have been employed. Most measures produce information suited to particular uses. Percent time measures, for instance, are sensitive to variations in the duration of particular EEG responses (e.g. Mulholland, 1962). Percent time information, however, is frequently ineffective in the experimental enhancement of these responses via BFB (e.g. Cleeland, Booker, & Hosokowa, 1971; Peper & Mulholland, 1970; Walsh, 1974). Other methods, such as spectral analysis (Banquet, 1973) and the Fourier transform (Hawkes & Prescott, 1973) yield a great deal of information about the central tendencies of the nonsinusoidal EEG waveform. In fact, the amount of information obtained is so great that its 'feedback' to human subjects is not usually possible. Some form of data reduction thus becomes necessary to make the feedback process manageable.

Hardt and Kamiya (1976a) observed that successful experimental enhancement of EEG responses occurred most frequently when the measure of integrated amplitude of the waveform was used. Brown (1970), Hardt (1974), and Kamiya (1971) all reported successful enhancement of the alpha rhythm using integrated measures. Lansky, Lansky, Zdenek, Indra, & Radil-Weiss (1979) noted that such integrated measures are related to the energetic content of the brain rhythm, and demonstrated the normality of the distribution of both integrated
scores and percent time scores of the EEG. They concluded that the choice of measurement should depend on its final use.

Toomin, Schandler, Spiegel, Freeman, Elder, and Silverberg (1979) noted that integration measures take into account the frequency-amplitude relationship inherent in the EEG. Technically, the square of the amplitude under a waveform equals its 'energy' (Bennet, 1960, pp. 149-164). Most frequently in the biofeedback literature, however, 'energy' is defined as 'power'. Power is the energy available within a system which performs the work seen. Power is normalized according to the Gaussian distribution (Bennet, 1960, pp. 37-54). Thus, since the measure of integrated amplitude of the EEG employs the differential between two sites through a load (electrode impedance, which is typically less than 5 Kohms), the term power is not inappropriate (Strong, 1979). The method of integration sums the area under the curve of the complex wavetrain of the EEG (Boas, 1966, pp. 37-54). Thus, power measurements of high reliability are practicable using modern digital equipment.

The activity of the two cerebral hemispheres is often asymmetric. This laterality effect has been related to handedness (Milner, 1967). Galin and Ornstein (1972) demonstrated a task-performance relationship in lateral asymmetry. Right hemisphere power is reduced during spatial performance tasks, while left hemisphere power is reduced during performance of verbal tasks. The reduction in power, it should be noted, is not necessarily indicative of a lack of activity in the suppressed hemisphere. Rather, it is
related to the shift from lower frequency higher amplitude (and thus higher power) activity to higher frequency desynchronous activity (with lower power). Attempts to artificially enhance lateral asymmetries have met with mixed success (Newman, 1980; Peper, 1971; Schwartz, Davidson & Pugash, 1976; Suter, Griffin, Smallhouse, & Whitlach, 1981).

A relatively small number of studies have attempted to train subjects in management of theta activity, with moderate success (Beatty, Greenberg, Deibler & O'Hanlon, 1974; Sittenfeld, Budzynski, & Stoyva, 1976). The irregularity and elusiveness of the theta rhythm in the EEG makes it a difficult response for BFB. Control of the sensorimotor rhythm, a signal which overlaps the alpha bandwidth and occurs over the motor cortex, has been found helpful in the reduction of epileptic seizure activity (e.g. Lubar, 1977; Sterman, 1973; Sterman, MacDonald, & Stone, 1974). Sheer (1975) reported on BFB enhancement of 40 Hz EEG activity, which he maintained was associated with a state of 'focused arousal' leading to facilitation of performance in other tasks. It has been further demonstrated that control of 40 Hz activity transfers to situations outside the BFB setting, with selective enhancement or suppression of the response possible (Bird, Newton, Sheer, & Ford, 1978a, 1978b; Ford, Bird, Newton, & Sheer, 1980). Further biofeedback research and training continues to be done with all of these psychophysiological cortical rhythms.

The vast majority of research in EEG biofeedback, however, has been focused upon the alpha bandwidth. As Berger first noted, alpha
is a (relatively) large magnitude, easily obtained EEG response, producable by nearly all normal subjects. Perhaps most significantly, the alpha rhythm responds in an extremely sensitive manner to sensory stimulation in various modalities (Albino and Burnand, 1964).

The nature of the alpha rhythm

The alpha rhythm is the most energetic or powerful brain wave response seen in the waking EEG. Yet the power of individual alpha waves within the 8-13 Hz bandwidth are unrelated to their individual frequency (Burdick, 1968). In other words, a great deal of variability in alpha power is seen within the alpha bandwidth, independent of the center frequency of the subject's alpha. The source of the rhythm, and of its variability, have been subjects of investigation for many years.

Jasper (1948) proposed that brain waves such as the alpha rhythm were produced by spontaneous fluctuations in the local excitability of large groups of neurons within and under the cerebral cortex. Such a proposal is a logical extension of EEG theory from Caton's work to the present. Some researchers, however, have attempted to explain the generation of alpha via other processes.

Kennedy (1959), for instance, argued that the alpha rhythm was an artifact of the mechanical pulsation of the electrically charged gel making up the brain, and was unrelated to actual nervous system activity. Miller (1968) disputed Kennedy's model of alpha's source, providing correlational evidence that the frequency of the macroscopic alpha waves was directly
synchronous with the activity of single neuronal units.

Nunez, Reid, and Bickford (1978) further demonstrated the relation of alpha activity to activity on the neuronal level, and described the standing wave characteristics of alpha which are similar to the physical parameters of seismic waves. The generation of alpha via summation of vast numbers of individual neuronal waveforms into standing brain waves has had other challenges, however. The role of the eyes in the alpha response have been tested, and oculomotor hypotheses proposed.

Lippold (1970; Lippold & Novotny, 1967), for example, proposed that the alpha rhythm was a result of tremors of the extraocular muscles occurring when the visual cortex is inactive. Thus, although alpha's occurrence would be related to sensory events, it would be a measure of the standing potential of the eye, not of activity in the occipital or parietal cortex. Lippold reported that warming the orbit of the eyes increases the alpha frequency from 9 Hz to 12 Hz. Other empirical tests of his hypothesis, however, failed to support it. Edmonston (1973) found that reduction of oculomotor tremor by means of local anesthesia enhanced alpha activity. The model predicts that tremor reduction would suppress alpha activity. Edmonston concluded that tremor therefore served to mask rather than to generate the alpha rhythm. This oculomotor model also fails to account for the presence of abundant alpha activity in the EEG of individuals
without eyes and/or ocular muscles (Upton & Payan, 1970; Butler & Glass, 1970). At present, Lippold's oculomotor hypothesis for the origin of alpha appears to be incorrect.

An alternate oculomotor explanation for alpha and alpha blocking has been developed by Mulholland and his colleagues (Dewan & Mulholland, 1969; Mulholland & Evans, 1965, 1966; Mulholland & Peper, 1971; Peper, 1970). The processes of visual accommodation, convergence, and pursuit tracking in visual attention coincide with blocking of alpha, similar to the effects of stimulation of the reticular formation. Peper (1970) contended that alpha enhancement was possible only when a person learned not "to look". This model allows for the presence of alpha in blind individuals, but does not fully explain alpha blocking in the same subjects. The notion, however, that individuals can selectively learn to inhibit alpha blocking, and thus learn to enhance alpha, is important to later BFB work.

Strong sensory input, such as bright lights, loud noises, or electrical shock, blocks the alpha rhythm in the EEG (Sokolov, 1963, 1965; Steklova, 1965). Alpha blocking was proposed as one behavioral expression of a more generalized response to novel stimuli, which was termed the orienting response. This nonspecific response, typified by increased general arousal of the central nervous system, fades with repetition of the stimulation—habituation is said to occur (Graham, 1973). Barry (1977) demonstrated that the biological significance of a stimulus is the primary factor controlling orientation. Biologically irrelevant stimuli
evoke less of a response than do relevant stimuli. Again, this concurs with Garcia's biological constraints model of the importance of stimulus relevance in learning (Garcia et al., 1969).

A popular model of cognitive processing contends that selective attention is given to stimuli in various sensory modalities (Boulter, 1977; Shiffrin & Grantham, 1974; Shiffrin, Craig, & Cohen, 1973; Treisman, 1969; Treisman & Davies, 1973). From a physiological perspective, this makes sense. The different afferent sensory pathway systems in the reticular formation of the hindbrain are organized differently, with widely different response rates. Stimulation within a single sensory system tends to inhibit activity in the other systems (Groves, Miller, Parker, & Rebec, 1973). Attention allocated to visual stimuli tends to block alpha production, particularly if the intensity of stimulation is high (Bridgwater, Sherry, & Marczynski, 1974). Auditory stimulation has been noted to have much less of a suppressive effect on alpha production (Jasper & Shagass, 1941). The idea that visual attention selectively suppressed alpha activity was a viable model for many years (e.g. Shagass, 1942; Shagass & Johnson, 1943). Research in BFB, however, has effectively demonstrated that under the proper conditions, both auditory and visual stimulation can have enhancing effects on alpha production.

Marks (1978) contended that the informational content of signals within the various sensory modalities need not necessarily be different. Visual information can be translated into auditory information or vibrotactile information, for example. To
some degree, such transformations of information across sensory modalities are demonstrable in EEG alpha enhancement BFB training.

**Alpha enhancement BFB**

The use of operant techniques to produce alpha enhancement has been concentrated within the past two decades, with successful enhancement initially reported using lights, tones, or combinations of the two (e.g. Brown, 1970, 1971; Hart, 1968; Kamiya, 1968, 1969, 1979; Lynch & Paskewitz, 1971; Mulholland & Runnels, 1964; Nowlis & Kamiya, 1970, 1972; Peper, 1970). Much of this early alpha BFB literature, however, was not concerned nearly as much with the objective form of the FB as with the subjective effects reportedly produced in human subjects. A brief review of early 'alpha state' investigations will illustrate some of the problems involved in descriptions of responses without adequate investigation of all of the parameters involved.

The early reports on alpha BFB referred to above suggested that enhancement produced a state of consciousness substantially different from that of normal waking arousal. The state was described as being one of deep relaxation, with attendant slowing of thought, loss of external time sense and a sense of "egoless" alert awareness. A great deal of attention was focused upon these claims: were they indicative of a method for changing consciousness via BFB, or were they related to other factors?
Beatty and Kornfeld (1972) demonstrated that alpha enhancement could occur independent of changes in breathing or the circulatory system. The 'alpha state' thus could not be attributed solely to induced hyperventilation and subsequent lightheadedness. If alpha was linked to relaxed subjective experiences, introduction of stressful conditions should attenuate alpha production. Orne and Paskewitz (1974), however, demonstrated that induced anxiety alters general arousal levels (increasing measures of heart rate and galvanic skin response rates) without noticeably suppressing alpha production. Frost, Burish, and Holmes (1978) reached similar conclusions: stress does not suppress alpha. Conversely, enhancement of alpha does not eliminate the sensation of distress reported by stressed subjects.

Travis, Kondo, and Knott (1975b) attempted to quantify subjective reports of alpha enhancement subjects. They found that while half their subjects found alpha enhancement to be relaxing, half did not. They contended that the act of sitting comfortably with eyes closed was relaxing in and of itself, without positing alpha enhancement as a necessary cause. Grynol and Jamieson (1975) found that alteration of contingent and noncontingent FB did not alter subjective reports of relaxation. The subjective effects were unrelated to actual alpha performance. Plotkin (1976a, 1976b, 1977, 1978, 1979; Plotkin, Mazer, & Loewy, 1976) has manipulated a number of variables related to alpha enhancement, and has concluded that the 'alpha state' is not a result
of alpha enhancement per se but rather of the BFB setting as used for alpha enhancement. Hardt and Kamiya (1976b) disputed some of Plotkin's methods. Subsequently, he adopted their methodological suggestions and still reached the same conclusions. In his model, Plotkin attributed the 'alpha state' to situational variables, including relative sensory deprivation (sitting in a soundproof booth), sustained attention to a monotonous light pattern or tone, suggestion and expectation of experiential changes, sensitization to internal processes, perceived success at the task augmented by FB, and tendencies to attribute state changes to the novel BFB training session. Plotkin also contended that the alpha response cannot actually be enhanced, relative to eyes-closed resting baselines, and that state changes must therefore be independent of levels of alpha production.

These disputes regarding alpha BFB also prepared the way for further investigations of the parameters of alpha enhancement. It has been demonstrated, for instance, that an external monetary reward increases the reinforcing value of contingent FB, producing superior alpha control (Brolund & Schallow, 1976; Kondo, Travis, & Knott, 1975). The interaction of FB and instructions in alpha enhancement is not as clear as for some other response systems. The effect of giving correct instructions regarding the task alone is similar to the effects of FB alone, using auditory FB (Beatty, 1972; Prewett & Adams, 1976). Hord and Barber (1971)
demonstrated that positive or negative performance information in the form of FB is necessary for selective control of alpha production. Power enhancement above baseline levels, however, required positive response consequences. Hord and Barber relied upon eyes-open baselines for comparison, and thus were able to demonstrate enhancement above initial levels.

Travis et al. (1974a, 1975a) investigated the biofeedback parameters of both eyes-closed and eyes-open alpha enhancement. They found that analog auditory FB produced superior eyes-closed enhancement of alpha. Binary auditory FB or analog visual FB both were found to be successful in the production of eyes-open alpha enhancement. Greater variability, and greater enhancement over initial performance, was seen with eyes-open. Alpha levels with eyes-closed prior to feedback, however, were higher than those achieved using eyes-open FB. This again relates to Plotkin's assertion that enhancement above eyes-closed resting baselines are not achievable. An alternate conclusion drawn by Travis et al., however, is that alpha enhancement is demonstrable only under conditions which would normally be expected to suppress alpha production.

Visual FB contingent upon the alpha activity of only one brain hemisphere produces superior control to that contingent upon the alpha production of both hemispheres (Mulholland & Eberlin, 1977). Variations in the interstimulus interval between the alpha response and onset of visual FB presentation
demonstrated that the shortest delays produced the best BFB control (Mulholland, Boudrot, & Davidson, 1979).

The studies discussed thus far have demonstrated that an enhancement of alpha with BFB training is possible under the proper conditions. None, however, have directly compared the relative effects of auditory and visual FB in producing alpha enhancement. Paskewitz and Orne (1973) demonstrated that auditory FB produced enhancement in eyes-open EEG alpha production only under conditions of dim ambient illumination. In total darkness, no enhancement was achieved. Lynch, Paskewitz, and Orne (1974b) compared the effects of contingent and noncontingent auditory and visual FB displays on alpha enhancement. Both contingent and noncontingent visual FB produced an enhancement over trials, although alpha levels were still lower than for eyes-closed resting baselines. Auditory FB, however, did not produce noticeable changes from baseline levels. Visual FB also allowed for differential control of alpha production (alternate periods of alpha "on" and alpha "off"), while auditory FB did not. It should be noted that the visual FB subjects practiced eyes-open alpha enhancement with dim light input (the red or green FB display panels). Auditory FB subjects were in total darkness with eyes open during training and testing.

Ancoli and Kamiya (1978) summarized the methodological findings in alpha BFB training, together with problems which make comparisons of findings obtained under different conditions difficult. Differences in equipment response characteristics and in definition
of alpha and alpha enhancement require specification within individual studies. The use of different measurement techniques, of different recording sites, and of different ambient sensory conditions leads to widely different results. The difference in results with eyes-open and eyes-closed has already been noted. Determination of baseline levels is quite different under the two conditions. Variation in training schedules, laterality of FB, and in FB parameters such as FB presentation (analog or binary), FB modality, and FB contingency should be stipulated. Selection of subjects also introduces variability in final outcomes. The criterion used needs to be precisely reported. The relevant parameters of the current study will be detailed in the Methods section of this paper.

Restriction of FB for alpha enhancement only to auditory or visual modalities is not explained by any of the preceding studies. An examination of tactile stimulation, its history in BFB, and its relation to alpha enhancement follows next.

Tactile stimulation and its relation to alpha enhancement

The different sensory nervous tracts which provide afferent information to the central nervous system are dissimilar not only in function, but in structure and method of operation as well (Granit, 1955). Rates of transmission are generally fastest in the exteroceptive sensory systems, vision and audition, slowest in the interoceptive systems, including the chemical senses of olfaction and gustation and the haptic senses of temperature, pressure, motion, and location (usually labeled tactile sensation). Garcia and Rusiniak (1977) proposed
that interoceptive perception was physiologically well suited to
the provision of FB about organismal integrity and in the acquisition
of new behavioral responses. Exteroceptive perception is adapted
biologically for use in the acquisition of food and in warning of
external threats to organismic survival.

For most of this century, the primary use of tactile sensation in
psychological research was as an aversive stimulus (e.g. Garcia et al.,
1970; Hull, 1943; Miller, 1969; Skinner, 1938; Wilcoxin et al., 1971),
usually electric shock. The importance of tactile stimulation in
appetitive learning has received less attention. Touch has not
remained empirically untouched, however.

Shiffrin et al. (1973) demonstrated that the degree of attention
necessary to detect a vibrotactile stimulus was minimal. Orientation
to the stimulus in the classical sense was not required. The
individual involved could continue to attend to auditory and visual
performance tasks while receiving information via tactual transmission.
Pomerleau-Malcuit and Clifton (1973) noted that responses to stimulation
in various modalities varied according to the state of consciousness
in human neonates. In the waking state, tactile stimulation
was not as arousing as auditory stimulation. Lechelt and Tanne (1976)
demonstrated that vibrotactile pulses were more accurately perceived
when received in the preferred hand than in the nonpreferred hand.
Tactile stimulation, rather than being primarily aversive, is frequently
reported as being pleasant to experience.
Tactile stimulation is preferred over other modalities of sensation by normal children, while schizophrenic and retarded children appear to actively dislike visual stimuli (Onwaki, Brahlek, & Stayton, 1973; Schopler, 1966). Vibratory stimulation served as an adequate reinforcer for operant conditioning of motor responses in a severely retarded child (Bailey & Meyerson, 1969). No decrement in performance was observed during a three-week posttreatment extinction period when vibrotactile reinforcement was withdrawn. Rehagen and Thelen (1972) developed methods to separately test the reinforcing values of vibration, the touch of the vibrator on the skin surface, and the sound produced by the vibrating device. Vibration was significantly more effective as a positive reinforcer for motor responses in retarded children, giving outcomes comparable to those obtained using food reinforcers. Clements and Tracy (1977) further demonstrated the value of tactile reinforcement in the control of classroom behavior. Tactile stimulation, and particularly vibrotactile stimulation, has been shown to be an effective response consequence in the control of different types of behavior.

Sherrick (1975) discussed the history and problems of vibrotactile stimulation systems. The difficulty of separating the auditory noise produced by most electromechanical vibrators from the tactile stimulus has also been noted by other researchers (Ormsby & Thompson, 1983; Rehagen & Thelen, 1972). A major problem of electromechanical vibrators which has been solved by use of high-speed solid-state electronic circuitry is slow response. Increasing the speed of response (and thus decreasing the interval between performance and reinforcement) beyond
a certain point, however, leads to the problem of mechanical overshoot. Solutions to this problem create the converse problem of overdamping. Even methods for description of vibrotactile stimulation have not been determined. Some reports specify cutaneous displacement amplitude, measured in G's by an accelerometer (e.g. Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969; Kirman, 1973). Unfortunately, the physical coupling for energy transmission at the skin surface is highly variable and poorly understood. More frequently, displacement amplitude is stated as a function of vibrator peak-to-peak voltage responsivity, with constant internal damping of the device and constant frequency of vibration (e.g. Ormsby & Thompson, 1983; Sherrick, 1975).

Impairments in other sensory systems (i.e. as with the blind and deaf) have been overcome via the transduction of energy into meaningful tactile pulses. Bach-y-Rita et al. (1969) and Geldard (1966) have done extensive work in the coding of visual information into tactile substitutes which kinetically vary over time. Their methods were designed to serve as an improvement over the static information from Braille and other such tactile systems for the blind. Kirman (1973) reported successful communication of human speech by means of tactile pulsations. Clearly, information can be conveyed as successfully by means of the tactile senses as by that of vision or hearing.

Tactile stimulation is infrequently used in BFB applications, however. The taxonomy of FB displays has not yet been systematically developed (Yates, 1980, p. 38). In fact, comparisons of the effectiveness of FB in different modalities is rarely performed
Such comparisons, when made, can be generalized only to the specific response task tested.

Blanchard and Young (1972), for example, compared the relative effectiveness of visual and auditory FB for the regulation of heart rate. No difference was noted for acceleration of the heart, but visual FB was slightly superior for deceleration. Alexander, French, & Goodman (1975) likewise compared auditory and visual FB for the reduction of EMG tension leading to relaxation. They found auditory FB to be superior for this response. However, their use of frontalis EMG as their dependent measure does not control for the necessary involvement of the eyes in the use of visual FB. Partially to test the degree of interaction between use of the eyes and frontalis tension, and also to compare the relative effectiveness of other types of FB for this response, Schandler and Grings (1974) developed means to provide tactile FB to biofeedback subjects. Their's was the first published method for providing tactile feedback within the biofeedback literature.

In single short-term BFB sessions, Schandler and Grings (1976) were able to train subjects to reduce EMG levels further using tactile FB than was possible without weeks of progressive relaxation training, a popular alternative to BFB. Auditory and visual FB did not produce similar rapid reductions in the EMG. In fact, visual FB tended to increase EMG activity in the frontalis area. Relaxation from tactile FB generalized to other muscle groups as well, while the effects of auditory FB did not generalize nearly so much. Tactile FB relaxation
showed evidence of transfer outside of the BFB setting, similar to the effect achieved via long-term progressive relaxation training.

Another comparison of tactile FB with FB in other modalities was made by O'Connell, Frerker, and Russ (1979). Tactile FB was found to be superior in the control of skin temperature in males but not females. EMG reduction with tactile FB was superior to that with auditory FB. Both were superior to the results of visual FB. For heart rate control, however, no differences in response were found dependent upon FB modality. Again, the characteristics of the response appear to determine the effectiveness of use of one or another modality of stimulation for FB in biofeedback tasks.

The unconditioned enhancement of EEG alpha via tactile stimulation was first reported by Travis and Barber (1938). While auditory sensation tended to have relatively little effect on alpha production, visual input tended to suppress alpha production. In a series of sensory discrimination tests, Kreitman and Shaw (1965) found that tactile stimulation significantly enhanced alpha production, irrespective of the specific form of the test. In some tests, auditory stimulation enhanced alpha while in others it suppressed it. For most subjects, visual discrimination resulted in alpha suppression, although for a few subjects its effects were enhancement of the response. Kreitman and Shaw measured alpha enhancement in terms of amplitude integration. They noted no significant differences in state of arousal contingent upon the modality of stimulation, monitoring forearm EMG as well as the frequency of the alpha rhythm. Slightly greater enhancement of alpha was achieved
with tactile stimulation with eyes-open than eyes-closed, although the alpha production with eyes-closed was greater than with eyes-open.

The evidence, then, appears to suggest that tactile stimulation naturally produces alpha enhancement, while auditory does not necessarily. Visual stimulation, on the other hand, is naturally related to alpha suppression. If, as Garcia and Rusiniak (1977) suggest, the best form for FB to take is that form most specific to the response, the use of auditory or visual FB for alpha enhancement in BFB sessions is not likely to produce the best results.

Statement of the problem

The EEG alpha enhancement BFB paradigm tested in the present study is based upon past research regarding alpha enhancement. It has been found that the response can be successfully learned in single BFB sessions of half-hour duration, using contingent FB (Travis, et al., 1974a). Clear instructions regarding the relationship of the FB to the response are also of use (Travis et al., 1974b). As noted, it is likely that relaxation aids, rather than results from, alpha enhancement (Plotkin, 1979). Eyes-open conditions tend to reveal the enhancement (Lynch, et al., 1974; Paskewitz & Orne, 1973; Travis et al., 1974a, 1974b), while eyes-closed conditions do not (Plotkin, 1979).

In the past, however, tactile FB has not been tested for alpha BFB applications. Instead, alpha enhancement BFB has relied exclusively upon auditory or visual FB, although tactile stimulation has a better empirical relation to the response than does stimulation in the form of sound or lights (Kreitman & Shaw, 1965; Travis & Barber, 1938).
The present study, therefore, compared the effectiveness of tactile, auditory, and visual FB modalities for the enhancement of EEG alpha power during single, 30 minute BFB sessions. All three modalities of FB were presented with both contingent and noncontingent relation to the response. It was predicted that tactile FB would produce the greatest enhancement of the response, auditory less of an enhancement, and visual FB would produce suppression of alpha power. Contingent feedback was expected to have more significant effects upon alpha production than would noncontingent feedback. Thus, various models of alpha biofeedback processes are tested within this study.
METHOD

Subjects

One hundred forty-three volunteers, composed roughly equally of public school children, college students, military personnel, business and working people, and retirees, ranging in age from 8 to 69 yrs served as the population from which the experimental sample was selected. The subjects self-selected the time of day for their session from a list of available openings (from 7 a.m. to 10 p.m.). Presence of one or more of the following criteria resulted in their rejection from the sample: prior history of BFB, meditation, or hypnotic training; use of psychoactive medication within 48 hrs. of the session; somatic illness; severe headache within 48 hrs. of the session; neurophysiological abnormalities or handicaps; insomnia within 48 hrs. of the session; claustrophobia or other emotional distress induced by sitting in a small, closed, soundproofed room; and high levels of muscle tension (EMG) artifact (greater than 75 uv through a lowpass Medcraft filter set for rolloff at 55 Hz) during pre-FB monitoring or for more than 10 sec at any time during the session.

Of the 63 subjects who passed the criteria, 30 males and 30 females were randomly assigned to receive tactile, auditory, or visual FB. Half of all subjects within each modality received FB which was contingent upon their performance; half received randomly varied
noncontingent FB. Thus, six treatment groups were created: contingent tactile (CT), contingent auditory (CA), contingent visual (CV), noncontingent tactile (NCT), noncontingent auditory (NCA), and noncontingent visual (NCV). See Table 1 for group breakdowns on demographic covariates of sex, age, handedness, and time of day chosen. The experimenter made special efforts to recruit as many left-handed subjects as possible; thus, 30% of the sample was sinistral.

Setting

A dual-shielded electrically isolated room with independent AC and DC power supplies was used for recording and training. Ambient electronic noise levels within the room averaged less than 200 µV/m of RF and UHF radiation, compared with average levels of 20 mV/m of radiation centered around line frequency (60 Hz) and its harmonics in the building outside the shielding. The shielded room was divided into two halves: a subject room, soundproofed and separated from the monitoring room by a dual-shielded door. A one-way mirror allowed the experimenter to observe subjects during the session, and a two-way intercom enabled subjects to voice problems or ask for assistance if desired.

The subject room contained the FB devices detailed below and a padded reclining chair with an electrode junction box behind it. A masked 50 W white light bulb above and behind the chair provided indirect ambient lighting, measured at 8 Ft-c intensity (average) off the subject's forehead. Similarly, an overhead ventilation fan served to provide 25 dB ambient white noise. A shelf located 1.5 m from the
Table 1.

Age (in years), Handedness, and Time of Day of Training for Subjects in each Biofeedback Treatment Group.

<table>
<thead>
<tr>
<th>Feedback modality</th>
<th>Tactile Contingent</th>
<th>Noncontingent</th>
<th>Auditory Contingent</th>
<th>Noncontingent</th>
<th>Visual Contingent</th>
<th>Noncontingent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
</tbody>
</table>

Key to table abbreviations:

L - left handed
R - right handed
M - morning (before noon)
A - afternoon (noon to 4 p.m.)
E - evening (after 4 p.m.)
subject's reclining eye level served to hold the visual FB device. All FB devices interfaced with control equipment in the monitoring room via shielded cables.

Apparatus

The tactile FB device consisted of a modified Dormeyer B24 253-A-1 solenoid sheathed in 10 mm of vinyl latex to eliminate auditory noise. The frequency of vibration was fixed at 30 Hz, and constant spring dampening ensured linear vibratory displacement at all levels of output (Ormsby & Thompson, 1983). The intensity of vibration was adjusted for each subject to provide minimally perceptible stimulation for 5 uv of alpha amplitude, with proportional increases up to maximal stimulation for amplitudes of 85 uv of alpha.

The auditory FB device consisted of a set of Supereex Pro B VI stereo headphones. The monophonic 1-KHz output of a Narco NB-141 auditory FB module was jumpered to provide bilateral stimulation, with stimulus parameters adjusted for each subject in a similar manner to that described for the tactile device.

The visual FB device consisted of two Narco NB-151 visual FB display panels, one with a red and one with a blue plastic screen (to control for color perception problems of subjects), driven by the lamp outputs of two Narco NB-122 filter modules. Photic output for each subject was adjusted to the parameters listed above.

01-P3 and 02-P4 silver/silver chloride electrodes and an earclip ground electrode provided left and right hemisphere raw EEG signals. Both left and right raw EEG were fed, via the electrode junction box
and shielded cable, to the input panel of a Medcraft Mark III 8-channel polygraph. Both channels were throughput with a gain of 25K to a matched pair of Narco NB-122 filters. The filters were set for unity gain, with a bandwidth from 8-13 Hz. The filters provided -20 dB rolloff below 6.5 Hz and above 14.8 Hz. The EEG alpha output from these filters was returned to the polygraph input panel through 25K attenuators to restore the original signal's original amplitude parameters. Both raw EEG and filtered alpha were displayed on four of the polygraph's channels, which were calibrated for 5 mm of pen deflection per 10 uv of EEG amplitude.

Both raw EEG and filtered alpha from both hemispheres were recorded on a Narco CDR-141 4-channel Physiotape recorder for later digital analysis. Alpha from alternate hemispheres was displayed on a Tektronix 7854 oscilloscope and the waveforms were analyzed for frequency and amplitude to ensure accuracy of filtering and signal interpretation (see Appendix A for the software used in the analysis).

A 10 Hz oscillator signal was randomly varied in amplitude and duration by passage through two Coulbourn S35-20 probability gates, a Coulbourn S42-10 sequential stepper, and custom circuitry. This random simulated alpha signal served to operate the FB circuitry for noncontingent FB subjects. The subject's alpha production from the contralateral hemisphere to the preferred hand operated the FB circuitry for contingent FB subjects. Continuous analog FB was provided in the respective modality for alpha (or simulated alpha) which exceeded the 5 uv threshold for minimal stimulation.
The recorded left and right hemisphere alpha from the Physiotape was run through two Coulbourn S76-22 cumulating resetting digital integrators set to provide 1 digital count per 1 mv-s of input, providing raw integral scores for both hemispheres. Integral scores were cumulated for 2.5 sec intervals, with interval totals then translated to EEIA standards and transmitted to a CDC Cyber 720 computer for storage and analysis.

Procedure

During electrode placement all potential subjects were screened via the selection criteria and were instructed for the BFB session in a room separate from the shielded experimental room. Appendix B is a transcript of the subjects' briefing and instructions). Rejected subjects were not informed of their lack of suitability for the study. Rather, they experienced the same treatment as experimental subjects, except that they all received noncontingent auditory FB and their EEG was not recorded on the polygraph or on tape. All subjects were briefed on the fundamentals of EEG alpha BFB training, and were repeatedly (during the intervals preceding the various data collection periods within the session) instructed to relax and enjoy the session. All subjects were asked to keep their eyes open at all times during the session; the experimenter monitored the subjects periodically to ensure compliance. Data collection during any period was stopped, the eyes-open instructions were repeated, and the period restarted any time a subject's eyes remained closed for longer than 3 sec. The subjects were instructed to attempt to increase the intensity of the FB provided
during FB periods; the relationship of increasing FB to increasing alpha was explained. The subjects were free at any time to ask questions about the procedure they were undergoing. Questions were also solicited by the experimenter in the breaks between data collection periods within the session.

Following electrode placement, individuals were seated in the subject room and their electrode leads connected to the junction box. The chair was then reclined and adjusted until the subject expressed physical comfort. The subject was then left alone in the room, and 2 min. of signal calibration and EMG screening took place. A 30 sec physical quieting period preceded each data collection period detailed below, to further reduce the likelihood of EMG artifact in the data record.

A 5 min. initial baseline (B1) was recorded for all experimental subjects following calibration and EMG screening. During this time the subjects sat with eyes-open and relaxed on their own, with no feedback presented.

The experimenter then presented the FB device, by assigned group, to the subject and, using calibrated 10 Hz sine waves, adjusted the stimulus intensity to levels appropriate for each subject. The tactile FB device was placed under the subject's preferred hand on the chair arm; pilot testing indicated that this position was the easiest for subjects to maintain. The auditory headphones were placed on the subject's head and adjusted for comfort. The visual FB displays were placed on the shelf within the subject's view.
A 5 min. free FB (FFB) period was then recorded, with the subject instructed that this period would allow time to adjust to the FB and to learn how to use it. Subjects were again preinstructed that an increase in FB stimulation was indicative of increased alpha production.

All subjects were then universally told that they were doing very well at the task of increasing their alpha production. Three additional 5 min. FB periods were then recorded (FB1, FB2, and FB3).

Finally, FB was turned off, the respective FB device was removed, and a 5 min. postbaseline (B2) period was recorded. Thus, each data collection period yielded a total of 120 integral alpha measures for each brain hemisphere.

The subject was then debriefed and all electrodes were removed. Any enhancement in alpha noted by the researcher was pointed out on the polygraphic record by the researcher, and the subjects were congratulated on their performance. Any remaining questions the subjects had were answered, except for those which related to specifics of the experimental design (i.e. contingency of FB, etc.). All subjects were assured that their performance was normal.

**Data reduction and analysis**

Left and right hemisphere raw integral alpha scores stored on the computer were maintained in separate data files for each subject.

**Calculation of period power and period power enhancement.** The raw integral scores for each period were adjusted for amplifier
gain and the length of the sampling interval; adjusted scores were then squared and summed to yield period power totals. (Appendix C describes the mathematical technique applied to derive period power from the original raw integral scores, according to the methods of Kendall and Stuart (1977, p. 372-396). The computer software used to perform the calculation of period power totals is listed in Appendix D. B1 power totals served as the baseline from which alpha enhancement within the other five periods of the session was derived. The difference between total alpha power production within each period and total alpha power production in the B1 period was calculated, and served as the dependent measure of alpha power enhancement. Positive increases in alpha power over the baseline level were defined as enhancements, while decreases in alpha power compared with the baseline level were defined as suppressions of alpha. Amplitude integration yielding power measures of alpha production is a physical transformation of the EEG producing values for normal populations of subjects which are normally distributed (Gasser, Bacher & Mocks, 1982; Rouse & Landresse, 1978).

Analysis of variance across conditions within periods. An analysis of variance of alpha power production within the B1 period was performed, to examine initial operant levels of the response. Additional analyses of variance of alpha power enhancement across conditions within each of the five periods following B1 were performed (see Appendix E for a listing of the computer software used to perform the analysis). Thus, each period within the session was
treated analytically as a separate trial, rather than as a repeated measure across the entire length of the session. This method of analysis of variance in the EEG is frequently used in the BFB literature (e.g. Lynch et al., 1974a, 1974b; Travis et al., 1974a, 1974b, 1975a, 1975b; Tyson, 1982).

Analysis of covariance across conditions within periods. The variables of sex (male or female), age (in yrs.), handedness (the response to the question, "Are you right or left handed?"), and time of day selected for training (morning, afternoon, or evening) were examined as covariates of the independent variable of FB treatment condition. Analyses of covariances across conditions within periods were performed (see Appendix F for a listing of the computer software used).

Quadratic predictors of power as a function of time. Raw integral scores for each period of the BFB session were corrected for amplifier gain and length of the sampling interval and squared to yield power scores for each of the 120 intervals within each period. These interval power scores were then analyzed using polynomial regression in the manner described by Kim and Koshut (1979). Using this new method of EEG analysis, quadratic predictors of alpha power production as a function of time for each treatment condition for each period were thus obtained. Linear transformations of alpha enhancement BFB data have been performed in the past, via the method of linear regression (Mulholland & Eberlin, 1977; Mulholland et al., 1979). Quadratic functions, however, are found to better approximate asymptotic curves than do lower order linear functions (Dingle, 1973,
pp. 31-63). Stimson, Carmines and Zeller (1981) demonstrated the statistical validity of the application of the polynomial regression technique to human behavior; the present study employed the method to improve the accuracy of data representation. The quadratic predictors of alpha power were then plotted and graphed on a Wang 2211 graphics terminal (see Appendix G for a listing of the computer software used to perform the polynomial regression analysis).
RESULTS

Left hemisphere EEG alpha power enhancement

EEG alpha power production in the left hemisphere did not differ significantly during the initial baseline (B1) period between the six treatment groups: contingent tactile (CT), contingent auditory (CA), contingent visual (CV), noncontingent tactile (NCT), noncontingent auditory (NCA), and noncontingent visual (NCV). Figure 1 shows the left hemisphere alpha power production for each group during B1, and thus serves as the baseline against which enhancement is measured. A slight general trend toward enhancement of alpha power over time is apparent in the initial rising inflection of the curves; for all but one group (NCV), however, the trend was asymptotic and began to fall off toward the end of B1.

Figure 2 shows discernably different alpha power production by the different treatment groups during the free FB (FFB) period (refer back to the B1 figure for subsequent left hemisphere comparisons). The alpha enhancement achieved by certain groups was significantly greater than that of others during FFB (see Table 2 for results of ANOVA). The CT group produced the greatest amount of alpha during FFB (see Table 3, column 2 for FFB alpha power production). The CT group also produced the greatest enhancement over B1 levels (the difference between the B1 column and the FFB column in Table 3).
Figure 1.
Initial baseline EEG alpha power production as a function of time.

(a) Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Noncontingent Feedback
Figure 2.
Free feedback EEG alpha power production as a function of time.

(a) Contingent Feedback

<table>
<thead>
<tr>
<th>Feedback modality</th>
<th>Tactile</th>
<th>Auditory</th>
<th>Visual</th>
</tr>
</thead>
</table>

(b) Noncontingent Feedback

Power (in $\mu^2$)

Time (in 2.5 sec intervals)
Table 2.
Analysis of Variance Results for EEG Alpha Power Enhancement across Conditions within Periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left hemisphere</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFB</td>
<td>3.522</td>
<td>.0079</td>
</tr>
<tr>
<td>FB1</td>
<td>2.728</td>
<td>.0287</td>
</tr>
<tr>
<td>FB2</td>
<td>2.811</td>
<td>.0250</td>
</tr>
<tr>
<td>FB3</td>
<td>2.218</td>
<td>.0656</td>
</tr>
<tr>
<td>B2</td>
<td>2.092</td>
<td>.0805</td>
</tr>
<tr>
<td><strong>Right hemisphere</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFB</td>
<td>4.029</td>
<td>.0035</td>
</tr>
<tr>
<td>FB1</td>
<td>3.321</td>
<td>.0109</td>
</tr>
<tr>
<td>FB2</td>
<td>3.995</td>
<td>.0037</td>
</tr>
<tr>
<td>FB3</td>
<td>3.148</td>
<td>.0145</td>
</tr>
<tr>
<td>B2</td>
<td>1.880</td>
<td>.1130</td>
</tr>
</tbody>
</table>

**Key to table abbreviations**

- FFB — Free Feedback
- FB1 — Feedback1
- FB2 — Feedback2
- FB3 — Feedback3
- B2 — Postbaseline
Table 3.
Group Means of Left Hemisphere EEG Alpha Power (in uv2) Produced within 5 minute Periods of Biofeedback Sessions.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Period</th>
<th>B1</th>
<th>FFB</th>
<th>FB1</th>
<th>FB2</th>
<th>FB3</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td></td>
<td>2579.17</td>
<td>6619.98</td>
<td>7306.27</td>
<td>9184.24</td>
<td>7631.16</td>
<td>6056.79</td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td>2497.21</td>
<td>2596.42</td>
<td>3279.07</td>
<td>3695.33</td>
<td>3426.86</td>
<td>2922.07</td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>2962.05</td>
<td>1863.07</td>
<td>1897.32</td>
<td>1961.33</td>
<td>2283.50</td>
<td>3433.34</td>
</tr>
<tr>
<td>NCT</td>
<td></td>
<td>1298.41</td>
<td>3501.69</td>
<td>5265.60</td>
<td>4085.03</td>
<td>4780.83</td>
<td>2746.22</td>
</tr>
<tr>
<td>NCA</td>
<td></td>
<td>1069.25</td>
<td>1311.24</td>
<td>1342.19</td>
<td>1280.13</td>
<td>1278.80</td>
<td>1460.36</td>
</tr>
<tr>
<td>NCV</td>
<td></td>
<td>2504.90</td>
<td>1983.23</td>
<td>2436.84</td>
<td>2456.54</td>
<td>2418.70</td>
<td>2501.76</td>
</tr>
<tr>
<td>Population mean</td>
<td></td>
<td>2150.33</td>
<td>2982.94</td>
<td>3587.88</td>
<td>3777.10</td>
<td>3636.64</td>
<td>3186.76</td>
</tr>
</tbody>
</table>

Key to table abbreviations

CT — Contingent tactile
CA — Contingent auditory
CV — Contingent visual
NCT — Noncontingent tactile
NCA — Noncontingent auditory
NCV — Noncontingent visual
B1 — Initial baseline
FFB — Free Feedback
FB1 — Feedback1
FB2 — Feedback2
FB3 — Feedback3
B2 — Postbaseline
The NCT group also produced a smaller but significant enhancement of alpha during this period. Table 4 details the enhancement (or suppression) of the alpha response which occurred in each period after B1. Alpha enhancement during FFB is shown in the first column. The CV group demonstrated the most highly significant suppression of alpha power seen during this period, while the NCV group also showed a significant suppression of alpha during FFB. Neither of the auditory groups showed significant changes from B1 levels during FFB. The enhancement of alpha response quantified in Table 4 was also apparent in examinations of the polygraphic record. As B1 alpha production was similar for all groups, Appendix H serves to represent the B1 alpha production of most subjects. Appendix I shows the enhanced alpha output characteristic of CT subjects during the various FB periods, and Appendix J similarly shows the characteristic suppression of alpha produced by CV subjects during FB periods.

The same patterns of enhancement and suppression of alpha power were apparent in the treatment groups during the first period of FB (FB1) (see Figures 1 and 3) as during the FFB period. During both the second FB (FB2) period (see Figure 4) and the third FB (FB3) period (see Figure 5), however, the CA group also demonstrated a significant enhancement of alpha power above B1 levels. The CT group continually showed the greatest enhancement. The CV group experienced the most alpha suppression, followed by the NCV group (see Table 4), during FB.
Table 4.

Mean Enhancement of Left Hemisphere EEG Alpha Power (in µV²) from Initial Eyes-open Baseline Group Mean.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Period</th>
<th>FFB</th>
<th>FB1</th>
<th>FB2</th>
<th>FB3</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>4062.19**</td>
<td>4727.10*</td>
<td>6605.98**</td>
<td>5051.99*</td>
<td>3477.62*</td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>99.21</td>
<td>781.86</td>
<td>1198.12*</td>
<td>929.66*</td>
<td>424.86</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>-1098.98**</td>
<td>-1064.73**</td>
<td>-1000.72**</td>
<td>-678.55*</td>
<td>471.29</td>
<td></td>
</tr>
<tr>
<td>NCT</td>
<td>2212.28*</td>
<td>3976.19*</td>
<td>2795.67*</td>
<td>3491.42*</td>
<td>1456.81*</td>
<td></td>
</tr>
<tr>
<td>NCA</td>
<td>241.99</td>
<td>272.94</td>
<td>210.88</td>
<td>209.55</td>
<td>391.11</td>
<td></td>
</tr>
<tr>
<td>NCV</td>
<td>-521.67*</td>
<td>-68.06*</td>
<td>-48.36</td>
<td>-86.20</td>
<td>-3.14</td>
<td></td>
</tr>
<tr>
<td>Population mean</td>
<td>832.61</td>
<td>1437.55</td>
<td>1626.77</td>
<td>1486.31</td>
<td>1036.43</td>
<td></td>
</tr>
</tbody>
</table>

* Mean differs significantly from population mean during period, p < .05, by LSD posttest method.

** Mean differs significantly from population mean during period, p < .05, by Tukey’s posttest method.

Key to table abbreviations

CT — Contingent tactile
CA — Contingent auditory
CV — Contingent visual
NCT — Noncontingent tactile
NCA — Noncontingent auditory
NCV — Noncontingent visual
FFB — Free Feedback
FB1 — Feedback1
FB2 — Feedback2
FB3 — Feedback3
B2 — Postbaseline
Figure 3.
Feedback EEG alpha power production as a function of time.

(a) Left hemisphere
Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Left hemisphere
Noncontingent Feedback
Figure 4.
Feedback EEG alpha power production as a function of time.

(a) Contingent Feedback

(b) Noncontingent Feedback
Figure 5.
Feedback EEG alpha power production as a function of time.

(a) Left hemisphere
Contingent Feedback

(b) Left hemisphere
Noncontingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

Power (in μV²)

Time (in 2.5 sec intervals)
During the postbaseline (B2) period, both the CT and the NCT group continued to demonstrate a significant enhancement of alpha power (as seen in Figure 6), although the continued enhancement of alpha was much greater in the CT group than in the NCT group. The mean alpha power production of the other treatment groups during B2 was not significantly enhanced (see Table 4). The enhancement achieved by the tactile groups was therefore significant not only during the treatment periods when feedback was given, but also continued during B2, when feedback was withdrawn.

The covariates of sex, age and handedness of individual subjects and of time of day of the BFB session did not significantly alter treatment outcomes for any period of the session in the left hemisphere.

In the left cerebral hemisphere, tactile FB produced large magnitude alpha enhancements during and after treatment. Visual FB resulted in large magnitude alpha suppressions only during treatment periods. In both these modalities, contingent FB had the most effect on alpha power. Auditory FB produced mixed results.

**Right hemisphere EEG alpha power enhancement**

Alpha power production in the right hemisphere did not differ significantly between the six treatment groups (see Figure 7) during the initial baseline (B1) period. In the right hemisphere the slight
Figure 6.

Postbaseline EEG alpha power production as a function of time.

(a) Left hemisphere
Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Left hemisphere
Noncontingent Feedback

Power (in µV²)

Time (in 2.5 sec intervals)
Figure 7.

Initial baseline EEG alpha power production as a function of time.

(a) Contingent Feedback

(b) Noncontingent Feedback

Feedback modality:
- Tactile
- Auditory
- Visual

Right hemisphere
Free feedback EEG alpha power production as a function of time.

(a) Contingent Feedback

(b) Noncontingent Feedback
Table 5.

Group Means of Right Hemisphere EEG Alpha Power (in uv^2) Produced within 5 minute Periods of Biofeedback Sessions.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Period</th>
<th>B1</th>
<th>FFB</th>
<th>FB1</th>
<th>FB2</th>
<th>FB3</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td></td>
<td>3241.41</td>
<td>8264.56</td>
<td>8219.23</td>
<td>10358.39</td>
<td>8832.01</td>
<td>6565.37</td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td>3118.79</td>
<td>3347.47</td>
<td>3980.98</td>
<td>4855.85</td>
<td>4575.00</td>
<td>4300.56</td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>3218.68</td>
<td>1877.20</td>
<td>2155.10</td>
<td>2249.82</td>
<td>2188.03</td>
<td>3837.10</td>
</tr>
<tr>
<td>NCT</td>
<td></td>
<td>1693.92</td>
<td>3444.58</td>
<td>5037.66</td>
<td>3447.99</td>
<td>4523.30</td>
<td>3029.23</td>
</tr>
<tr>
<td>NCA</td>
<td></td>
<td>1122.13</td>
<td>1811.10</td>
<td>1113.09</td>
<td>1301.37</td>
<td>1303.77</td>
<td>1507.93</td>
</tr>
<tr>
<td>NCV</td>
<td></td>
<td>2654.71</td>
<td>2167.49</td>
<td>2658.18</td>
<td>2746.09</td>
<td>2739.42</td>
<td>2264.35</td>
</tr>
<tr>
<td>Population mean</td>
<td></td>
<td>2508.27</td>
<td>3485.40</td>
<td>3860.71</td>
<td>4159.75</td>
<td>4026.92</td>
<td>3584.09</td>
</tr>
</tbody>
</table>

Key to table abbreviations

CT — Contingent tactile
CA — Contingent auditory
CV — Contingent visual
NCT — Noncontingent tactile
NCA — Noncontingent auditory
NCV — Noncontingent visual
B1 — Initial baseline
FFB — Free Feedback
FB1 — Feedback1
FB2 — Feedback2
FB3 — Feedback3
B2 — Postbaseline
The general trend toward alpha enhancement with the passage of time during B1 was also asymptotic (as in the left hemisphere) for most groups.

The most alpha was produced by the CT group during the free FB (FFB) period (see Figure 8), over twice as much power as that produced by any other group (see Table 5). The enhancement in alpha power achieved by the CT group was significantly greater than that seen in all other groups, although the NCT group also significantly enhanced alpha power during FFB (see Table 6). The CV group experienced the most significant suppression of alpha during FFB, followed by the NCV group. Neither the CA or the NCA group demonstrated significant alpha power enhancement during this period.

Again during the first FB period (FB1), the CT group demonstrated the greatest alpha enhancement (see Figure 9). The enhancement achieved by both the CT and the NCT groups was significant. The CV group again experienced the greatest suppression of alpha (see Table 6). During FB1, however, the NCA group also experienced alpha suppression, with the NCV group's enhancement far below population norms. A slight but nonsignificant enhancement in alpha power was apparent in the CA group.

The patterns of enhancement and suppression of alpha power during the second FB (FB2) period (see Figure 10) were similar to those which occurred during FFB. The CT group experienced the greatest alpha enhancement, while the CV group had the most alpha suppression (see Table 6). During this period, however, the enhancement of alpha
### Table 6.

Mean Enhancement of Right Hemisphere EEG Alpha Power (in $\mu$v$^2$) from Initial Eyes-Open Baseline Group Mean.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Period</th>
<th>FFB</th>
<th>FB1</th>
<th>FB2</th>
<th>FB3</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td></td>
<td>5023.15**</td>
<td>4977.82**</td>
<td>7116.97**</td>
<td>5590.60**</td>
<td>3323.97*</td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td>228.68</td>
<td>862.19</td>
<td>1737.05*</td>
<td>1456.21*</td>
<td>1181.77</td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>-1341.49**</td>
<td>-1063.59**</td>
<td>-968.87**</td>
<td>-1030.66**</td>
<td>618.42</td>
</tr>
<tr>
<td>NCT</td>
<td></td>
<td>1750.66</td>
<td>3343.74*</td>
<td>1753.08*</td>
<td>2829.38*</td>
<td>1335.31</td>
</tr>
<tr>
<td>NCA</td>
<td></td>
<td>688.97</td>
<td>-9.04*</td>
<td>179.24</td>
<td>181.64</td>
<td>385.79</td>
</tr>
<tr>
<td>NCV</td>
<td></td>
<td>-487.22**</td>
<td>3.48*</td>
<td>91.39</td>
<td>84.71*</td>
<td>-390.36*</td>
</tr>
<tr>
<td>Population mean</td>
<td></td>
<td>977.13</td>
<td>1352.43</td>
<td>1651.48</td>
<td>1518.65</td>
<td>1075.82</td>
</tr>
</tbody>
</table>

* Mean differs significantly from population mean during period, $p < .05$, by LSD posttest method.

** Mean differs significantly from population mean during period, $p < .05$, by Tukey's posttest method.

**Key to table abbreviations**

- CT -- Contingent tactile
- CA -- Contingent auditory
- CV -- Contingent visual
- NCT -- Noncontingent tactile
- NCA -- Noncontingent auditory
- NCV -- Noncontingent visual
- FFB -- Free Feedback
- FB1 -- Feedback1
- FB2 -- Feedback2
- FB3 -- Feedback3
- B2 -- Postbaseline
Figure 9.

Feedback EEG alpha power production as a function of time.

(a) Right hemisphere

Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Right hemisphere

Noncontingent Feedback
Figure 10.
Feedback EEG alpha power production as a function of time.

(a) Right hemisphere
Contingent Feedback

(b) Right hemisphere
Noncontingent Feedback
Feedback EEG alpha power production as a function of time.

(a) Right hemisphere

Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Right hemisphere

Noncontingent Feedback

Power (in $\mu^2$)

Time (in 2.5 sec intervals)
power achieved by the CA group was significant, and nearly as great as that demonstrated by the NCT group.

During the third FB (FB3) period, the CT group again had the most enhancement and the CV group the most suppression of alpha (see Figure 11). A less significant enhancement was achieved by the NCT and the CA groups (see Table 6); the NCT group's enhancement of alpha power was twice that achieved by the CA group during FB3.

During the postbaseline (B2) period, only the CT group's alpha enhancement was significant (see Figure 12). The alpha power of the NCV group was significantly suppressed during B2. Most other groups showed a slight general trend toward enhancement over time during B2, as in B1; the NCT group's alpha power, however, sharply declined over time during this period (see Table 6). Only for the CT group was the enhancement of alpha in the absence of feedback significant.

As for the left hemisphere, the covariates for individual subject demographics and for time of the session had insignificant effects on treatment outcomes during all periods of data collection.

In the right cerebral hemisphere, then, tactile FB use produced large magnitude enhancements of alpha during FB periods, while visual FB use produced large magnitude suppressions of alpha power. The
Figure 12.

Postbaseline EEG alpha power production as a function of time.

(a) Contingent Feedback

Feedback modality
- Tactile
- Auditory
- Visual

(b) Noncontingent Feedback
enhancement produced by CT feedback was even greater than in the contralateral hemisphere, while NCT feedback did not have as large an effect on the right as on the left. Only the CT group's enhancement persisted through B2. While CV feedback did not suppress alpha power as much in this hemisphere as in the left, it was more effective than NCV feedback for suppressing alpha. In this hemisphere, however, the NCV group continued to show alpha suppression even during B2. Auditory FB, as for the left hemisphere, produced mixed results.
DISCUSSION

The advice of Beck and Peper (1979) regarding their own history of unforeseeable mishaps in the performance of BFB research was relevant to the present study, and fortunately was familiar to the researcher prior to its inception. Of the 143 potential subjects who volunteered for participation, three were preteenage boys who decided within the first 15 minutes of their sessions that BFB was boring, and that they wished to leave. Immediately. (No correlation with FB modality was noted.) Another volunteer remembered, 27 minutes into her half-hour, that she was claustrophobic, and nearly tore the recording electrodes from her scalp in her hasty retreat to a washroom. Several other (apparently) awake and alert volunteers fell into heavy slumbers within moments of sitting in the reclining chair. Frequent equipment redesigns turned over a dozen early BFB sessions into pilot tests. These mishaps and their ilk, however, added color to the entire proceeding thes without jeopardizing the overall data collection process. The twin random factors of human quirkiness and irrationality cannot safely be ignored in any line of psychological research, nor were they in this study.

The results of the present BFB study indicate that tactile FB was the most effective form of feedback available for the enhancement of EEG alpha power within the constraints of the particular eyes-open biofeedback paradigm used for training. The effect of tactile FB
on the alpha production of both hemispheres was very similar, irregardless of the handedness, age, or sex of the subject involved. Although the laterality of tactile stimulation varied (the vibrator was placed under and stimulated the preferred hand) and was always unilateral, enhancement of alpha as a result was bilateral. The visual modality FB which was alternately used led to suppression rather than enhancement of alpha. Again, the effects occurred bilaterally, with no interaction from individual subject covariates. For both of these two FB modalities, the highest magnitude (and most significant) effects occurred within those groups whose FB varied contingently dependent upon their actual alpha performance.

The introduction of contingent tactile FB led to superior alpha enhancement throughout the remainder of the BFB session, not only during periods of FB presentation, but also continuing during the non-FB posttreatment baseline period in both hemispheres. In effect, the effects of alpha training with CT feedback transferred to a nonfeedback condition. It should be noted that noncontingent tactile FB produced a weaker transfer of training beyond periods of FB presentation, and only in the left hemisphere. The alpha production of most other groups during the posttraining period regressed toward the mean baseline levels recorded at the beginning of the session. The noncontingent visual FB group, however, also demonstrated a weak transfer effect in the right hemisphere. The suppression of alpha in this hemisphere without FB was similar in magnitude to the largest suppression which occurred during NCV feedback presentation. A
similar, but nonsignificant transfer of training was also seen in the left hemisphere alpha response of the NCV group during B2. Within both FB modalities, the onset of the effect was very rapid (rapid enhancement with tactile FB; rapid suppression with visual FB). The magnitude of these opposing responses to FB stimulation was relatively high.

Auditory FB presentation did not produce a simple unified response pattern like those seen with tactile or visual FB. Enhancement of alpha with contingent auditory FB occurred very slowly, and the response magnitude never equalled that produced by tactile FB. In fact, enhancement as a result of noncontingent auditory FB was initially greater than that of contingent auditory FB (although responses to both forms of FB were weak). The CA feedback group never demonstrated alpha suppression. Suppression of alpha during presentation of NCA feedback, however, occurred within one period, in the right hemisphere. During all other FB periods, the NCA group demonstrated weak and nonsignificant enhancement of alpha power.

The results of this study to some degree duplicate the findings of researchers (Kreitman & Shaw, 1965; Travis & Barber, 1938) whose work was published prior to the conceptualization of BFB as a viable strategy for self-regulation of physiological responses. Tactile, auditory, and visual signals were presented to subjects and the effects of the signals on the alpha response were noted. The non-BFB studies cited, however, relied upon random presentation of stimulation and assumed that changes in alpha production were reflexive responses to sensory input. The BFB paradigm assumes that physiological performance
is not necessarily reflexive, but can also be modified voluntarily (Kamiya, 1968, 1969). Unfortunately, the norm in most specialized fields is not to reference or even acknowledge investigations reported by individuals working outside of the specialty. Biofeedback, however, as a conceptualization of mind/body interaction and as a demonstrable methodology for behavioral change, requires familiarity with divergent sources of information. BFB theorists have a noted tendency to be pragmatic (Yates 1980, pp. 5-81). That which works continues to be used; that which does not is discarded. Unfortunately, this pragmatic approach frequently results in the abandonment of difficult research questions and a tendency to assume that certain problems cannot be resolved (Dworkin & Miller, 1977). A hiatus in the BFB literature regarding alpha enhancement studies is apparent from the author's reading of the last several year's journals. Since the publication of Ancoli and Kamiya's (1978) synopsis of past alpha BFB, less than thirty reports of alpha enhancement BFB projects have been published. This is compared with more than a hundred reports per year published about alpha BFB in the early 1970's. The phenomenon of alpha BFB conditioning has proven to be more problematic than was originally anticipated. As a result, the response of alpha enhancement has been largely abandoned by BFB workers in favor of simpler responses with clearer clinical applicability. Most of the problems which were encountered in the early studies of alpha BFB training, however, are not unsolvable. Comparisons between studies are possible, if the conditions used in training are clearly stated and understood.
The present study essentially investigated research questions which have not been widely investigated in the BFB literature. The basis for prediction of treatment outcomes came not primarily from past BFB work, but from other fields of psychological research. In the author's opinion, isolationism is not a viable intellectual stance upon which to base meaningful research, and has been avoided as much as possible within the current text. An accurate explanation of the results of the present study is impossible without a synthesis of evidence and viewpoints from a number of insular areas throughout the scientific literature. A number of issues introduced earlier in this paper will now be reexamined in light of these results.

One popular theoretical view in BFB assumes that the primary function of feedback is the provision of additional information for use in cognitive control of internal processes (Gaarder, 1979; Meichenbaum, Schwartz, 1975, 1979; Singer, 1976). Some problems of this model have already been mentioned. If FB were only an information source, any sensory stimulus capable of entering cognitive awareness should be as capable of conveying information as any other stimulus (Marks, 1978). The modality of stimulation chosen for FB should therefore be irrelevant. This is not, however, the case. As demonstrated by past research (e.g. Alexander et al., 1975; Blanchard & Young, 1972; Schandler & Grings, 1976) performance on specific BFB tasks varies as a function of the modality in which FB is presented. Although cognitive factors probably play important roles in the mediation of BFB effects, such as in the interpretation of instructions (e.g. Beatty, 1972;
Plotkin, 1976a; Singer, 1976), the anticipation of BFB effects (e.g. Chatterjee & Eriksen, 1962; Lang & Twentyman, 1976), and the like, they do not account for numerous effects demonstrated throughout the BFB literature.

In the current study, the utilization of different modalities of FB had directional effects on the alpha production of BFB subjects, although each subject received the same briefing and instructions. Even the subjective reports of individuals who received the same type of FB varied widely. Some people said that the auditory tones presented as FB were "soothing", others that they made them want to laugh, and several said that they were "annoying". Most subjects reported that the tactile vibrations they felt were "nice" or "relaxing", but some stated that they felt uncomfortable as a result of receiving them. Most subjects did not like the visual FB displays, and said that they felt "more relaxed" when they ignored the lights. (This strategy concurs with the oculomotor model for alpha enhancement proposed by Mulholland & Peper, 1971, although even this selective "not looking" did not result in alpha enhancement). Subjective reports from subjects also have little or no relation to their actual psychophysiological performance on BFB tasks (London & Schwartz, 1980). Individuals demonstrate no innate ability to determine their brain wave state, so responses such as alpha enhancement are ideal choices for tests of the effects of FB on performance. Cognitive models of the BFB process do not seem to adequately account for the specific findings of this study as well as do other models, and thus are discounted.
Models which explain BFB as a conditioning process are also popular. The two primary processes distinguished in conditioning involve classical, or reflexive, responses and instrumental, or operant responses (Skinner, 1938). The issue of biological preparedness for learning certain types of responses (Garcia et al., 1969; Garcia et al., 1970) was also introduced earlier. The results of the present study will now be examined within the behavioral frameworks of conditioning models.

Furedy (1979; Dawson & Furedy, 1976; Furedy & Poulos, 1976) offered a classical conditioning model to explain BFB effects. In this model, physiological responses are reflexively elicited by unconditioned stimuli (either internal or external) which an organism receives. In order for learning to occur, FB is paired a number of times with a particular unconditioned stimulus. If the response is later elicited by the FB in the absence of the unconditioned stimulus, the response is said to be a conditioned reflex. This model is simple, both to describe and to test. Unfortunately, it does not agree even with the results of Furedy's (1979) own research, which was detailed earlier. In the present study, if FB served as a conditioned stimulus, an enhancement of the alpha response should have occurred only in the contingent FB groups, for whom FB presentation coincided with performance of the response. The random presentation of FB which characterized the noncontingent condition should not have produced a conditioned association. Yet both noncontingent tactile and visual FB presentation produced effects which were similar to,
but smaller in magnitude to the responses produced by presentation of contingent tactile and visual FB. On the other hand, if the enhancement seen in these groups were solely the result of unconditioned responses to FB stimulation, no difference in performance should be apparent in performances between the NCT, NCA, or NCV groups. The random FB which these three groups received was controlled by solid-state electronic probability gates, with a thirty percent probability of FB presentation at any given moment within the feedback periods. Roughly the same length of stimulation was received by subjects in each of the noncontingent FB groups. Yet performances differed significantly between these groups as well. The classical conditioning BFB model does not fully account for the alpha responses noted in the present study, and thus will be set aside for now, to allow a consideration of operant models applicable to the results.

The simplest models of operant conditioning assumed that stimulation of any type could be equivalently used for reinforcement of any selected response, so long as presentation of the stimulus was made contingent upon performance of the response (e.g. Hull, 1943; Skinner, 1959). Subsequent research, however, has revealed a high degree of specificity in particular stimulus-response relationships (e.g. Breland & Breland, 1961; Rozin & Kalat, 1971). Organisms appear to be adapted to respond vigorously to some stimuli, to ignore or infrequently respond to others, and to require a lengthy period of time to learn the value of still other stimuli. Seligman (1970) has postulated that these differential response patterns are indicative of a
biological preparedness continuum for the learning of particular relationships about performances and their consequences. Garcia and Rusiniak (1977) extended this notion to learning via BFB. They proposed that certain types of FB were more appropriate to serve as reinforcers for particular physiological responses than were other possible types of FB. The present study tested this model, using three different modalities of FB, and effectively demonstrated its veracity.

The different sensory systems possessed by humans respond in very different ways to the physically different types of signals which have been categorized as tactile, auditory, visual, and chemical (Granit, 1955). Although stimulation in the tactile modality has a long history in psychology in aversive conditioning, the sense of touch has also been investigated for use in appetitive conditioning. Vibrotactile stimulation in particular has been found to be an effective reinforcer for a number of different operant responses (e.g. Bailey & Meyerson, 1969; Clements & Tracy, 1977; Rehagen & Thelen, 1972). Tactile stimulation has also been effectively used as an aid for individuals suffering impairments in their other sensory systems (e.g. Bach-y-Rita, et al., 1969; Geladard, 1966). In BFB, however, provision of feedback has relied almost exclusively upon the auditory or visual modalities, although neither type of FB has been shown empirically to be a superior form of information transduction (Schandler & Grings, 1978). In fact, for the response of EMG reduction, tactile FB use
led to superior performance, compared with the results of auditory or visual FB (Schandler & Grings, 1976).

Tactile stimulation has been demonstrated to have superior enhancement effects on EEG alpha production (Kreitman & Shaw, 1965; Travis & Barber, 1938). The present study, however, is the first to use tactile FB in a biofeedback paradigm in an attempt to train subjects in the voluntary enhancement of alpha.

The response of alpha enhancement is simple to describe and relatively easy to measure, but is not so simple to explain (Thompson & Newton, 1983). Light input was once assumed to 'automatically' block alpha (Adrian & Matthews, 1934). Alpha production has been presumed to be indicative of a lack of visual attention, with alpha blocking (with alpha replaced by beta activity) a sign of visual attention and orientation to external stimulation (Sokolov, 1965). Since synchronous alpha waves frequently appear with near simultaneity in both brain hemispheres, it has been proposed that a pacemaker mechanism is active, probably located in a midbrain area where lateral functions are less widely segregated (Green, 1979). Andersen and Andersson (1968) reviewed previous research related to the origin of the alpha rhythm. They proposed that the rhythmic spindles emitted by thalamic nuclei are related to alpha generation, and indicative of recurrent inhibitory processes used in the central control of sensory information processing. Cortical activation following afferent input, initiated within the reticular formation (e.g. Moruzzi & Magoun, 1949), would then be balanced by efferent inhibition. This has proven to be the case, for
the tactile, auditory, visual, and olfactory senses (see review in Thompson, 1967, pp. 289-292). The brain, and the measure of its activity used in the present study, the EEG, are governed by reciprocal processes of activation and inhibition which are jointly used in an internal system of homeostatic feedback control.

A comprehensive description of the neuroanatomy of human sensory systems would be overly lengthy and somewhat extraneous to the purpose of this paper (for an introduction to the subject, refer to Watson, 1981, pp. 69-160). The thalamocortical structures active in the three sensory modalities used for FB in the present study are, however, relevant to an explanation of treatment outcomes. The ventral posterior nuclei and their projections in the parietal cortex are involved in tactile sensation and perception. The medial geniculate nuclei and their projections in the temporal cortex are involved in auditory sensation and perception. The lateral geniculate nuclei and their projections in the occipital cortex are involved in visual sensation and perception. It has been noted that stimulation within one modality tends to inhibit receptivity within other modalities (Groves et al., 1973). Stimulation within only one FB modality therefore should lead to increased activity in the associated thalamocortical structures and to reduced activity in the structures associated with other modalities. In the relatively deprived sensory environment utilized for alpha BFB training, the instructions to and expectations of the subject tend to make the FB signal very salient to the subject (Plotkin, 1979).
Ancoli and Kamiya (1978) discussed EEG electrode placement as an important variable in the determination of treatment outcomes in alpha BFB. Occipital and occipital-parietal placements (such as the O1-P3 and O2-P4 placements used herein) tend to provide optimal measures of alpha activity. Although the 10-20 cranial electrode placement system used internationally is somewhat inexact, and perhaps in need of revision (Binnie, Dekker, Smit & Van der Linden, 1982), it does allow for relatively accurate determination of cortical electrical activity below the intact scalp, and for rough localization of that activity.

Since alpha generation is most often discussed as a sign of inhibition of visual attention (e.g. Mulholland & Peper, 1971), and since alpha activity is most prevalent over the occipital lobes during such inhibition, it follows that activity in other cortical areas resulting from stimulation in nonvisual modalities should facilitate alpha production. In fact, this effect has been previously demonstrated (e.g. Kreitman & Shaw, 1965). Beta waves predominate in the EEG during visual stimulation, while alpha waves predominate during vibrotactile stimulation. Alpha and beta activity alternates during auditory stimulation.

The parietal electrode placement used in this study was near the projection area for touch, and somewhat farther from the projection area for audition, while the other electrode in each hemispheric pair was located over the projection area for vision (Thompson & Newton, 1983). The power data reported in Tables 2 through 5, therefore, are differential measures of the activity in the cortical areas associated
with taction and vision, and to a lesser degree audition, the three modalities chosen for FB.

The superior alpha enhancement achieved using contingent tactile FB can be explained by a synthesis of the information above. Contingent tactile FB activates the parietal cortex and inhibits activity in the other sensory areas. The alpha rhythm occurs as a function of the inhibition of the visual cortex. The power differential between the activated parietal cortex (with higher frequency lower power activity predominant) and the inhibited visual cortex (with lower frequency higher power alpha activity predominant) is thus very high during tactile FB. The power differential between the temporal cortex activated by contingent auditory FB and the inhibited visual cortex is not as directly measured by the chosen electrode placement, and thus the enhancement in power observed is smaller in magnitude. Activation of the occipital cortex during visual FB blocks alpha production (without triggering a complementary high power rhythm in the other sensory areas), and the subsequently lower power differential between the recording sites is seen as a suppression of alpha power.

None of the physiological evidence offered thus far, however, accounts for the transfer of enhancement training noted in the CT feedback group. Although Garcia and Rusiniak (1977) suggested that proprioceptive FB (such as that provided by vibrotactile stimulation) is better suited to responses requiring low levels of arousal (such as alpha enhancement), this still does not fully explain why such training should transfer beyond the FB condition better than do other
forms of training. It was noted earlier, however, that perception of individual tactile stimuli requires little effort on the part of the subject, making attention to other stimuli easier to achieve (Shiffrin, et al., 1973). Perception of auditory and visual signals requires greater effort, making other stimuli more difficult to attend to. Thus, Thompson and Newton (1983) postulated that ambient tactile stimulation that subjects received in compound with contingent tactile FB was readily associated with the FB, while ambient auditory and visual stimulation was not as readily associated with the respective auditory and visual FB. In the non-FB postbaseline period, only the ambient stimuli remained, and FB was removed. Second-order conditioning of ambient tactile stimuli to tactile FB could have occurred, accounting for the transfer of alpha enhancement training observed (see Rescorla, 1973, for an introduction to second-order conditioning). Essentially, it can be hypothesized that ambient tactile stimulation became a secondary reinforcer for alpha enhancement with primary reinforcement provided by contingent tactile FB. For other types of FB requiring greater attention, ambient stimulation was not as salient.

The results are thus best explained by an operant model of BFB. The model discussed takes into consideration the biological processes involved in alpha enhancement responses to explain effects observed during treatment, and to explain posttreatment transfer of training.

An analysis of the results of the present EEG biofeedback study leads to the conclusion that contingent tactile stimulation is the
prime choice for FB for alpha enhancement, with superior effects to those achieved using more traditional auditory or visual FB signals.

The future role of tactile FB in other areas of biofeedback is open to speculation. The effectiveness of vibrotactile stimulation in the production of two responses related to relaxation (EMG reduction and EEG alpha enhancement) suggests that the human organism is adapted to find such stimulation relaxing. Other forms of tactile stimulation could also be adapted to use within BFB sessions. The effects of subtle changes in temperature, pressure, and elasticity of various tactile FB devices should be tested. And, although the development of devices utilizing olfactory and gustatory stimulation for FB would be difficult (for instance, separating actual FB from the lingering chemical traces of FB), some responses might best be learned through their use. The author suggests that the choice of FB modality for specific BFB applications should be made based upon the characteristics of the response. Rather than arbitrarily selecting a particular type of FB because it is cheap or readily available, practitioners should determine whether a particular type of FB is appropriate, both to the response and to the individual who voluntarily chooses to perform the BFB task of self-regulation.
Appendix A: TEKTRONIX Micro Language Program used for Oscilloscopic Waveform Analysis

000 SCOPE AQS STORED MEAN-
001 P-P PAUSE PAUSE
002 MID FREQ PAUSE PAUSE
003 000 GOTO

This program acquires an amplified EEG signal input from the Medcraft polygraph, stores it, centers and expands it for clarity of measurement, then calculates the peak-to-peak voltage and the frequency of the EEG signal. The frequency and amplitude parameters for raw EEG amplified alpha within the ranges and methods defined for this study are a bandwidth between 8 Hz and 13 Hz and a peak-to-peak amplitude between 500 mv and 2.125 v. The program then repeats its operation for another sample of the subject's EEG.
Appendix B: Briefing and Instructions to Subjects

"Through the process of biofeedback, we'll look at a little bit of what's going on inside your head, and give you some information about your brain's activity that you're not normally aware of. So please have a seat here; I'll sit behind you and hook up these four monitoring electrodes to your scalp while I explain exactly what it is that you'll be doing. Have you ever really tried to relax?

"Well, that's what I want you to try and do in a few minutes, once I've gotten you hooked up so we can look at your brainwaves. To do that, I'll first measure your head, to locate the proper sites for the electrodes. I'll be measuring your brainwaves—what's called your EEG—and looking for a particular type of brainwaves called alpha. Most researchers think alpha is produced when you are in a state of 'relaxed wakefulness': with your eyes open (not asleep), but as calm and unconcerned as possible. You produce alpha on and off all day long—more of it, the more relaxed you are. I want you to put your troubles away for awhile and see if you can't make your brain slow down a bit.

"I'm going to monitor sites on each side of your head, in the back here (the occipital region) and forward here (the parietal region), where lots of alpha is usually produced. This will give me an idea of the action on in each side, or hemisphere, of your brain. I'll clean a site with some alcohol—does that feel cold?—and rub in some electrode cream to increase the conductivity of your scalp. The alpha waves I'm looking for are very tiny (less than 1/10,000 of a volt), so I have to have a good contact here to even be able to pick them up. If you can picture yourself and 30,000 other people all hooked up to a flash-light bulb, all of your alpha waves together might be powerful enough to light it up. Yet your brain is more than powerful enough to direct everything you do. Amazing, isn't it?

"Next, I take the electrode—this little silver disc with a wire on it—and put it on your scalp, then stick it down with this collodion. This is a special glue that will keep the electrode from moving around or falling off while you're getting biofeedback, but it comes right off when I clean you up at the end. Ready for the next one?

"After I monitor your alpha waves for awhile as you try to relax on your own, I'm going to give you some scientific help in relaxing. You're going to get biofeedback of your brain's alpha waves. They'll be amplified to make them easier to notice, and relayed back to you so that you can feel/hear/see them (as appropriate to the treatment group). The larger your alpha waves are, and the longer they last, the more relaxed your brain is. So, when you feel/hear/see your alpha waves, I want you to try to make them stronger/higher/brighter, and keep them big as long as possible. You can't expect them to stay big for very long, especially at first, so don't worry if the feedback fades or goes away completely. Just keep trying to relax, and it'll come back. That's the whole idea of biofeedback today: you already know how to relax; the feedback you feel/hear/see only helps you to know when you're doing well at it. The more relaxed, the more alpha; the more alpha, the more feedback you get. Any questions?"
Appendix C: The Method of Derivation of Period Power Measures from Raw Integrated Amplitude Measures

\[ t = 2.5 \text{ sec} = 1 \text{ interval} \]
\[ 120 t = 5 \text{ min} = 1 \text{ period} \]
\[ 720 t = 30 \text{ min} = 1 \text{ session} \]

Power = \( v^2 \sum_{i=1}^{2} (v^2 \Delta t) \) = integrated alpha power per period.

\( e = \) integrated alpha power per period, in \( \text{mv}^2 / \text{period} \);

\( n = \) integrated alpha for the \( i \) interval, in \( \text{mv-sec} \) (raw data measure);

\( m = \frac{n}{t} = \) average integrated alpha for the \( i \) interval, in \( \text{mv} \);

\( e = \frac{m}{t} = \) average integrated alpha output for the \( i \) interval, in \( \text{uv} \), compensating for amplifier gain;

\[ e = (2.5 \text{ sec}) \sum_{i=1}^{120} e^2 = (2.5 \text{ sec}) \sum_{i=1}^{120} (m_i)^2 = (2.5 \text{ sec}) \sum_{i=1}^{120} (n_i)^2 \]

\[ = (2.5 \text{ sec}) \sum_{i=1}^{120} (25 \text{ K})^2 = 625 \text{ M} \sum_{i=1}^{120} (2.5 \text{ sec})^2 \]

\[ e = \frac{1}{1562.5} \sum_{i=1}^{120} (n_i)^2 \]
Appendix D:  BASIC Language Program used to Compute Period Power.

```
00100 DIM A(12), L(12)
00150 FOR Y = 1 TO 12
00200 A(Y) = 0
00250 NEXT Y
00300 PRINT "INPUT FILE NAME";
00350 INPUT F1$
00400 FILE #1 = F1$
00450 MARGIN #1, 135
00500 DELIMIT #1,(CR)
00550 ON ERROR GOTO 02010
00600 INPUT #1, C1$
00650 L1$ = C1$(11:14)
00700 R1$ = C1$(17:20)
00750 L2$ = C1$(32:35)
00800 R2$ = C1$(38:41)
00850 L3$ = C1$(53:56)
00900 R3$ = C1$(59:62)
00950 L4$ = C1$(74:77)
01000 R4$ = C1$(80:83)
01050 L5$ = C1$(95:98)
01100 R5$ = C1$(101:104)
01150 L6$ = C1$(116:119)
01200 R6$ = C1$(122:125)
01250 LET L(1) = (VAL(L1$)) * 2
01300 LET L(2) = (VAL(R1$)) * 2
01350 LET L(3) = (VAL(L2$)) * 2
01400 LET L(4) = (VAL(R2$)) * 2
01450 LET L(5) = (VAL(L3$)) * 2
01500 LET L(6) = (VAL(R3$)) * 2
01550 LET L(7) = (VAL(L4$)) * 2
01600 LET L(8) = (VAL(R4$)) * 2
01650 LET L(9) = (VAL(L5$)) * 2
01700 LET L(10) = (VAL(R5$)) * 2
01750 LET L(11) = (VAL(L6$)) * 2
01800 LET L(12) = (VAL(R6$)) * 2
01810 FOR U = 1 TO 12
01815 LET L(U) = L(U) / 1562.5
01820 NEXT U
01850 FOR Z = 1 TO 12
01900 A(Z) = A(Z) + L(Z)
01950 NEXT Z
02000 GOTO 00550
02010 F2$ = "S" + F1$
02050 FILE #2 = F2$
02100 MARGIN #2, 100
02150 DELIMIT #2,(CR)
02175 PRINT #2,"SUBJECT ",F1$
02200 FOR W = 1 TO 12
02250 PRINT #2 USING "####.###",A(W)
02300 NEXT W
02350 CLOSE #1
02400 CLOSE #2
02450 END
```
Appendix E: SPSS Compiler Program used to Perform Analysis of Variance of EEG Alpha Power Enhancement across Conditions within Periods.

RUN NAME ANOVA FOR FEEDBACK MODALITY EFFECTS
FILE NAME MULTI
VARIABLE LIST CONDITION, SEX, AGE, HAND, LEFTBA, RIGHTBA, LEFTFF, RIGHTFF, LEFTFA, RIGHTFA, LEFTFB, RIGHTFB, LEFTFC, RIGHTFC, LEFTBB, RIGHTBB/
INPUT FORMAT FIXED
(15X,A2,2X,A1,1X,F2.0,1X,A1/F10.3/F10.3/F10.3/
F10.3/F10.3/F10.3/F10.3/F10.3/F10.3/F10.3/F10.3)
N OF CASES UNKNOWN
COMPUTE ENLFF=LEFTFF-LEFTBA
COMPUTE ENLFA=LEFTFA-LEFTBA
COMPUTE ENLFB=LEFTFB-LEFTBA
COMPUTE ENLFC=LEFTFC-LEFTBA
COMPUTE ENLBB=LEFTBB-LEFTBA
COMPUTE ENRFF=RIGHTFF-RIGHTBA
COMPUTE ENRFA=RIGHTFA-RIGHTBA
COMPUTE ENRFB=RIGHTFB-RIGHTBA
COMPUTE ENRFC=RIGHTFC-RIGHTBA
COMPUTE ENRBB=RIGHTBB-RIGHTBA
RECODE CONDITION("CT"=1)("NT"=4)("CA"=2)
("NA"=5)("CV"=3)("NV"=6)
RECODE SEX ("M"=1)("F"=2)
RECODE HAND ("L"=1)("R"=2)
RECODE AGE (LOWEST THRU 19=1)(20 THRU 39=2)(40 THRU HIGHEST=3)
VALUE LABELS CONDITION(1)CT(2)CA(3)CV(4)NCT(5)NCA(6)NCV
MISSING VALUES AGE, SEX, HAND (0)/LEFTBA TO RIGHTBB (0)/
ENLFF TO ENRBB (BLANK)/
READ INPUT DATA
COMMENT THIS SECTION CONTAINS ARTIFACTS OF PAST ANALYSIS
ONEWAY LEFTBA BY CONDITION(1,6)/RANGES=TUKEY(.05)/
RANGES=LSD(.05)/
STATISTICS ALL
OPTIONS 6
ONEWAY RIGHTBA BY CONDITION(1,6)/RANGES=TUKEY(.05)/
RANGES=LSD(.05)/
STATISTICS ALL
OPTIONS 6
ONEWAY ENLFF BY CONDITION(1,6)/RANGES=TUKEY(.05)/
RANGES=LSD(.05)/
STATISTICS ALL
OPTIONS 6
ONEWAY ENLFA BY CONDITION(1,6)/RANGES=TUKEY(.05)/
RANGES=LSD(.05)/
STATISTICS ALL
OPTIONS 6
OneWay ENLFB BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENLFC BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENLBB BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENRFF BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENRFA BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENRFB BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENRFC BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6

OneWay ENRBB BY CONDITION(1,6)/RANGES=Tukey(.05)/
RANGES=LSD(.05)/
Statistics All
Options 6
Appendix F: SPSS Compiler Program used to Perform Analysis of Covariance of EEG Alpha Power Enhancement across Conditions within Periods.

RUN NAME
FILE NAME
VARIABLE LIST
INPUT FORMAT
N OF CASES
COMPUTE
COMPUTE
COMPUTE
COMPUTE
COMPUTE
COMPUTE
COMPUTE
COMPUTE
RECODE
RECODE
RECODE
RECODE
VALUE LABELS
MISSING VALUES
READ INPUT DATA
COMMENT
ANOV
STATISTICS
OPTIONS
ANOV
STATISTICS
OPTIONS
ANOV
STATISTICS
OPTIONS
ANOV
STATISTICS
OPTIONS
ANOV
STATISTICS
OPTIONS
ANOV
Appendix F (continued)

**ANOV**
- ENLFC BY CONDITION (1,6) AGE (1,3)/
- ENLFC BY CONDITION (1,6) SEX (1,2)/
- ENLFC BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENLBB BY CONDITION (1,6) AGE (1,3)/
- ENLBB BY CONDITION (1,6) SEX (1,2)/
- ENLBB BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENRFF BY CONDITION (1,6) AGE (1,3)/
- ENRFF BY CONDITION (1,6) SEX (1,2)/
- ENRFF BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENRFA BY CONDITION (1,6) AGE (1,3)/
- ENRFA BY CONDITION (1,6) SEX (1,2)/
- ENRFA BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENRFB BY CONDITION (1,6) AGE (1,3)/
- ENRFB BY CONDITION (1,6) SEX (1,2)/
- ENRFB BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENRFC BY CONDITION (1,6) AGE (1,3)/
- ENRFC BY CONDITION (1,6) SEX (1,2)/
- ENRFC BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL

**ANOV**
- ENRBB BY CONDITION (1,6) AGE (1,3)/
- ENRBB BY CONDITION (1,6) SEX (1,2)/
- ENRBB BY CONDITION (1,6) HAND (1,2)/

**STATISTICS OPTIONS**
- ALL
Appendix G: SPSS Compiler Program used for Polynomial Regression of Raw Interval Integrated Amplitude Measures.

RUN NAME POLYNOMIAL REGRESSION PROGRAM: FEEDBACK MODALITY
DATA LIST FIXED/1 ID 01-05(A),SP1 06,BA 07-08(A),SP2 9-10,
LBA 11-14,SP3 15-16,RBA 17-20,SP4 21-23,TBA 24-26,
SP5 27,FF 28-29(A),SP6 30-31,LFF 32-33,SP7 34-36,
RFF 37-41,SP8 42-44,TFF 45-47,SP9 48,FA 49-50(A),
SP10 51-52,LFA 53-56,SP11 57-58,RFA 59-62,SP12 63-65,
TFA 66-68,SP13 69,FB 70-71(A),SP14 72-73,LFB 74-77,
SP15 78-79,RFB 80-83,SP16 84-86,TFB 87-89,SP17 90,
FC 91-92(A),SP18 93-94,LFC 95-98,SP19 99-100,
RFC 101-104,SP20 105-107,TFC 108-110,SP21 111,
BB 112-113(A),SP22 114-115,LBB 116-119,SP23 120-121,
RBB 122-125,SP24 126-128,TBB 129-131/
N OF CASES UNKNOWN
MISSING VALUES SP1 TO SP24 (0)/TBA1 TO TBB2(0)/LBA, RBA, LFF, RFF,
LFA, RFA, LFB, RFB, LFC, RFC, LBB, RBB(999)/
READ INPUT DATA
Appendix G (continued)

**COMMENT**
THE FOLLOWING SECTION PERFORMS THE DATA ANALYSIS

**REGRESSION**
VARIABLES=LBASQ,LFFSQ,LFASQ,LFBSQ,LFCSQ,LBBSQ,TBA1 TO TBB2/
REGRESSION=LBASQ WITH TBA1 TO TBA2(1) RESID=0/
REGRESSION=LFFSQ WITH TFF1 TO TFF2(1) RESID=0/
REGRESSION=LFASQ WITH TFA1 TO TFA2(1) RESID=0/
REGRESSION=LFBSQ WITH TFB1 TO TFB2(1) RESID=0/
REGRESSION=LFCSQ WITH TFC1 TO TFC2(1) RESID=0/
REGRESSION=LBBSQ WITH TBB1 TO TBB2(1) RESID=0/

**OPTIONS**
2,3,6

**STATISTICS**
2,7

**REGRESSION**
VARIABLES=RBASQ,RFFSQ,RFASQ,RFBSQ,RFCSQ,RBBSQ,TBA1 TO TBB2/
REGRESSION=RBASQ WITH TBA1 TO TBA2(1) RESID=0/
REGRESSION=RFFSQ WITH TFF1 TO TFF2(1) RESID=0/
REGRESSION=RFASQ WITH TFA1 TO TFA2(1) RESID=0/
REGRESSION=RFBSQ WITH TFB1 TO TFB2(1) RESID=0/
REGRESSION=RFCSQ WITH TFC1 TO TFC2(1) RESID=0/
REGRESSION=RBBSQ WITH TBB1 TO TBB2(1) RESID=0/

**OPTIONS**
2,3,6

**STATISTICS**
2,7
Appendix H: Representative 10 sec Samples of Raw EEG and Filtered Alpha from Initial Baseline Period from a Subject in the Contingent Tactile FB Group

$O_1-P_3$ filtered alpha

$O_2-P_4$ filtered alpha

$O_1-P_3$

$O_2-P_4$

20 uv | 1 sec
Appendix I: Representative 10 sec Samples of Raw EEG and Filtered Alpha from Free Feedback Period, Showing Enhancement of Alpha Produced by a Subject in the Contingent Tactile FB Group
Appendix J: Representative 10 sec Samples of Raw EEG and Filtered Alpha from Initial Baseline Period from a Subject in the Contingent Visual FB Group

\begin{align*}
&O_1-P_3 \text{ filtered alpha} \\
&O_2-P_4 \text{ filtered alpha}
\end{align*}

20 uv 1 sec
Appendix K: Representative 10 sec Samples of Raw EEG and Filtered Alpha from Free Feedback Period, Showing Suppression of Alpha Produced by a Subject in the Contingent Visual FB Group.
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