

Self-Regulation of Occipital

Alpha Asymmetry

A thesis submitted in partial fulfillment
of the requirements for the degree of Masters of Arts
in the Department of Psychology,
The University of Manitoba.

By

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B.A. 1978, The University of Manitoba

SELF-REGULATION OF OCCIPITAL ALPHA ASYMMETRY

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A dissertation submitted to the Faculty of Graduate Studies of
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MASTER OF ARTS

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Abstract

Research has shown that the cerebral hemispheres differ in function, with the left hemisphere predominantly involved with verbal functions and the right hemisphere with spatial functions. Moreover, a relationship between specific cognitive tasks and patterns of alpha (8 - 13 Hertz) asymmetry has been established. Further, studies employing various biofeedback techniques have demonstrated self-regulation of patterns of alpha activity with one study reporting a correlation between particular self-regulated patterns of alpha asymmetry and subjective reports of specific cognitive activity. Such evidence has prompted suggestions that the patterning of neural activity underlies the emergence of cognitive and subjective experience, and that hemispheric differences in processing information could underly lateralization of cognitive functioning. As a majority of the biofeedback studies in this area have utilized a method of feedback necessitating simultaneous modification of the EEG activity of both hemispheres (pattern biofeedback), it has not been possible to isolate and study specific hemispheric differences that may occur in the learning of differential control of alpha activity. The purpose of this study was a) to investigate interhemispheric differences occurring during differential control of alpha activity; b) to determine whether hemispheric differences in activity would be evidenced in response to the feedback task, possibly indicating hemispheric differences in processing, and c) to determine whether subjective reports of cognitive state would vary depending on the specific hemisphere receiving contingent feedback.

To this end, two groups of subjects, each composed of right-handed males, experienced proportional auditory feedback for increases in alpha

activity. One group received feedback contingent upon the alpha activity of the right hemisphere; the second group received feedback contingent upon the alpha activity of the left hemisphere. Bilateral occipital EEGs were recorded for all 30 subjects during two training sessions. Each session was composed of four blocks of training trials, each trial lasting 60 seconds. The EEG activity from each hemisphere was filtered for 8 - 13 Hertz activity and time spent in alpha was accumulated on two clock counters. These alpha time scores were used to determine the degree of alpha laterality due to the contingency manipulation (C-Laterality) and due to hemispheric reactivity (H-Laterality). Prior to the first training session, a standardized measure of hand and eye dominance was taken. Following the final training session, all subjects were given a Cognitive Strategies Questionnaire to assess their cognitive strategies during training.

The results indicated: that the contingency manipulation differentiated the right trained from the left trained group during both feedback and nonfeedback trials; that hemispheric reactivity was similar in both groups during feedback trials; that groups differed during nonfeedback trials, with differences mainly due to variance of the noncontingent hemispheres rather than between the contingent hemispheres; that the contingency manipulation did not significantly differentiate contingent from noncontingent samesided hemispheres during feedback or nonfeedback trials; that feedback trials uniformly differed significantly from nonfeedback rest trials. Further, the results indicated that groups did not differ on the test of lateral dominance and that subjective reports of cognitive strategies employed did not differ between groups.

In general, the study indicated that the contingent hemispheres generated more alpha activity than their noncontingent mates, resulting in specific patterns of asymmetry. For both right and left trained groups the development of patterns of asymmetry (higher alpha levels in the trained than in the nontrained hemispheres) were similar during feedback trials though not during nonfeedback trials. Contrary to previous reports subjects did not have difficulty increasing alpha levels in the left hemisphere. Further the findings indicated that same-sided hemispheres, whether contingent or noncontingent, generated similar amounts of alpha activity. Moreover, caution must be exercised when generalizing from a specific set of data, as the contingency manipulation, which effectively differentiated the trained from the nontrained mated hemispheres, did not effectively differentiate the trained from the nontrained same-sided hemispheres. Finally, the findings indicated that although specific patterns of alpha asymmetry were generated, specific correlated cognitive activities were not reported.

Introduction

Recent theory and research have suggested that the two cerebral hemispheres may differentially process information (Gazzaniga, 1974; Semmes, 1968). This was initially proposed after studies on brain damaged (Blakemore & Galconer, 1967) and split-brain subjects (Sperry, 1969) indicated that the left and right hemispheres differed in function. Research on intact human subjects (Dimond & Beaumont, 1976) has supported the findings that the left hemisphere is predominantly involved with verbal, numerical, and other analytical functions, while the right hemisphere is predominantly involved in spatial, musical, and other holistic functions. Recently, several researchers (Butler & Glass, 1974; Galin & Ornstein, 1972; 1975) have demonstrated a very strong correlation between the afore-mentioned differences in function and asymmetry in the electroencephalogram (EEG). Hemispheric asymmetries in the amplitude, frequency, and power of the alpha bandwidth (8 - 13 cycles/second) most sensitively and reliably reflect this correlation (Galin & Ornstein, 1975). Further, findings in biofeedback research have recently shown that subjects can be trained to produce asymmetrical patterns of alpha activity (O'Malley & Conner, 1972) and reports have indicated that particular patterns of asymmetry were correlated with subjective reports of particular cognitive modes (Schwartz, Davidson, & Pugash, 1976). These findings all suggested a strong correlation between cognitive function and underlying patterns of neural activity. In much of the previous biofeedback research in this area, subjects received feedback for the activity of both hemispheres simultaneously; one hemisphere for

increases in alpha activity, the other hemisphere for decreases in alpha activity. It was, therefore, not clear whether the reported patterns of alpha asymmetry and, specifically, patterns of asymmetry correlated with cognitive activity, would occur if feedback was provided for the alpha activity of only one hemisphere. Moreover, if, as has been suggested (Dimond & Beaumont, 1976; Semmes, 1968), hemispheric differences in the processing of information do underly differences in cognitive functioning, then, since cognitive functioning has been correlated closely with characteristic patterns of the EEG, it may be possible to determine the relationship between hemispheric differences in processing and characteristic patterns of the EEG by studying the basis of these patterns, i.e., the EEG of each hemisphere. Biofeedback, a method of training that enables an individual to gain some control over physiological responses that may not be otherwise amenable to direct control, can be used to study the EEG activity of each hemisphere. The present study proposed to use the biofeedback method to determine whether alpha asymmetry would occur when biofeedback was provided for the alpha activity of only one hemisphere, and whether the patterns of asymmetry were correlated with cognitive activity. The design enabled evaluations to be made of the alpha activity of each hemisphere, alpha asymmetry between the hemispheres, and cognitive mode during training. Further, this design allowed for a partial assessment of the utility of the biofeedback method as a tool to investigate hemispheric differences.

Hemispheric Differences in Cognitive Functions

Clinical and neurosurgical evidence. Hemispheric differences in cognitive functioning were determined initially through studies correlating

specific behavioral disorders with lesions in specific areas and from examining behavioral changes following surgical removal of specific anatomical areas. It has been determined that lesions of the left hemisphere selectively impair those functions associated with language (Blakemore & Falconer, 1967; Milner, 1962; Warrington & James, 1967), while lesions of the right hemisphere have been linked with deficits in spatial relations (Milner, 1968), musical ability (Bogen, 1969; Luria, 1973), and visio-constructive achievements (Milner, 1954). Further, lesions in the left posterior temporal lobe have been correlated with mathematical difficulties and speech deficits (Luria, 1954; Williams, 1970). Left frontal lesions have been correlated with speech fluency deficits; while lesions in the left parieto-occipital area have been associated with reading deficits (Milner, 1965; Williams, 1970). Right temporal lesions have been correlated with musical deficits (Kimura, 1964) and right parietal lesions with visual perceptual difficulties (Gloning, Gloning, & Hoff, 1968). Surgical removal of part or all of the right hemisphere (right temporal lobectomy) has been correlated with severe impairment on performance of visual and tactile mazes (Milner, 1965), and severe impairment of musical abilities (Gordon, 1974). Removal of all or part of the left hemisphere has been correlated with the severe impairment of verbal abilities (Gordon, 1974; Milner, 1965).

Split-brain evidence. Important evidence of hemispheric differences in performance of cognitive tasks has come from behavioral studies of split-brain patients.¹ Gazzaniga, Bogen, and Sperry (1965; 1967),

1

The split-brain preparation involves the transection of the corpus callosum, the anterior commissures and the hippocampal commissures (Sperry, 1968).

Gazzaniga and Sperry (1967), and Sperry (1968) have reported that split-brain individuals demonstrate a left hemisphere superiority for language, mathematical, and analytic tasks, and a right hemisphere superiority for spatial tasks and musical patterns. Recently, studies have suggested that the right hemisphere also has some language functions (Levy, 1976; Levy, Nebes, & Sperry, 1971; Levy & Trevarthen, 1976; Levy, Trevarthen, & Sperry, 1972) and that the left hemisphere has limited spatial relations functions (Levy-Agresti & Sperry, 1968). However, Levy (1976), in a review of the literature, has indicated that the language function of the right hemisphere is very limited in that an internal language system is for the most part absent, while the left hemisphere has ability in a spatial relations task only when stimuli can be simply labelled. This was elegantly demonstrated during a series of studies on split-brain individuals. The studies employed chimeric stimuli, which are two different half-stimuli joined at the midline. When these stimuli were presented tachistoscopically to split-brain individuals, each hemisphere perceived a different, but complete stimulus. The manual response of a subject to an array of choices indicated to which stimulus that subject was responding (Levy, Trevarthen, & Sperry, 1972; Levy, 1976). These studies used different types of chimeric stimuli (e.g., faces, shapes, objects). Response choices were either verbal (e.g., names of faces, objects, etc.), or visual (e.g., arrays of faces, etc.) and responses were made totally with one hand, or split between hands. The results showed that for visual responses, when either hand could be used to indicate a response, the right hemisphere controlled the choice 87% of the time regardless of the nameability of the stimulus. Choices controlled by the left hemisphere

were dominant when vocal naming responses were used and only for those stimuli that were well known. When the task demands were changed such that response choices were either pictures or words that rhymed with the chimeric stimuli (e.g., if shown a rose, correct choice would be toes) the left hemisphere stimulus was responded to in all conditions. These results again illustrated the differences between the hemispheres, i.e., the right hemisphere was dominant in visual and spatial tasks, the left hemisphere in verbal and language tasks.

While the studies previously cited are very suggestive of functional differences between the hemispheres, caution must be exercised in generalizing to a normal population. Each of the studies mentioned has used patients with some type of brain damage, and thus, the results may be confounded by the effects of radical surgery undergone by some of these individuals, or by secondary neurological disturbances associated with the primary disorder. It is therefore important to establish evidence of functional differences between the hemispheres in a normal population.

Experimental evidence. Lateralization of function in normal non-clinical right-handed subjects (see Appendix A) has been reported by a number of researchers (Dee & Fontenot, 1973; Dimond & Beaumont, 1976; Duyne & Scanlan, 1974; Hines & Satz, 1974; Kimura, 1966; 1967; Kimura & Durnford, 1976; White, 1972; White & White, 1975). Many researchers (Cohen, 1972; Geffen, Bradshaw, & Wallace, 1971; Kimura, 1966; Klatsky, 1976; McKeever & Huling, 1971a; 1971b) employing either accuracy of responding or correct number of responses as the response measure, have reported a right visual field (left hemisphere) advantage for verbal

stimuli presented tachistoscopically, whether the response was manual or vocal. Under similar testing condition, where response measures were either reaction time (White & White, 1975) or number of correct responses, several researchers (Geffen et al., 1971; Kimura, 1966; 1976; Klatsky & Atkinson, 1971; White & White, 1975) have reported a right hemisphere advantage for nonverbal stimuli (pictures, faces, and stimuli that could not be verbally encoded) and for tests of spatial location.

Similarly, functional asymmetry has been reported using dichotic listening tasks. When differences between the hemispheres were measured in terms of greater accuracy of recall, Bryden (1967; 1970), Hines and Satz (1974), and Kimura (1961; 1967) all reported a left hemisphere advantage for verbal material. Musical stimuli have also been presented dichotically. Subjects were required to sing the target stimulus or to choose from four binaurally presented alternatives, with hemispheric differences measured in terms of accuracy of recall. Kimura (1961; 1967) reported a right hemisphere advantage for musical tasks, Gordon (1974) reported a right hemisphere advantage for chord recognition, and Halperin, Nachson, and Carman (1973) reported that the right hemisphere was specialized for non-temporal tasks.

The results of these studies, coupled with evidence from the clinical and split-brain studies, strongly suggest that the left hemisphere is functionally specialized for language and analytic functions, whereas the right hemisphere is specialized for musical, spatial, and other holistic functions. The questions as to why this specialization should have occurred, the underlying neural processes involved, and the similarities or differences between the hemispheres in these processes, have not yet been fully

determined. Researchers (Dimond & Beaumont, 1976; Semmes, 1968) have suggested that hemispheric specialization arises from differences in the neural organization of or between the hemispheres. However, no firm evidence has yet been found to document this.

Electrophysiological Correlates of Hemispheric Differences in Cognitive Function

Recently, there has been a great deal of research attempting to link electrophysiological events with cognitive experience. Researchers have studied both the average evoked potential and the EEG in an attempt to correlate asymmetries in neural activity with specific cognitive experiences.

Average evoked potentials. There have been some reports of differences in the average evoked potential (AEP) recorded from the left and right hemisphere of right handed individuals. Andreassi, Okamura, and Stern (1975) examined hemispheric differences in the average visual evoked potential as a function of stimulus location (i.e., an X in the right visual field, left visual field, or at fixation). The authors reported that for stimuli in the right visual field, the latencies of components P_1 and N_2 were shorter in the left hemisphere. For stimuli in the left visual field, the latencies of these components were shorter in the right hemisphere. There were no latency differences for stimuli presented at fixation. There were no amplitude differences. The authors suggest that AEP hemispheric asymmetries can result from simple stimulus location.

Further, type of stimulus--verbal and non-verbal--has been reported to affect AEP asymmetry for both visual and auditory evoked potentials. Neville (1974) reported significantly shorter latencies to dichotically

presented digits for the later components of the auditory evoked potential (N_2 , P_2) from the left than from the right hemisphere. She also reported a tendency for shorter latencies (N_2 , P_2) to nonverbal clicks from the right hemisphere than from the left. These latency differences, however, were not significant. There were no significant amplitude asymmetries reported for the non-verbal condition, but dichotic verbal stimuli elicited AEPs of significantly greater amplitude from the left hemisphere than from the right. Analysis of AEPs to verbal and non-verbal stimuli presented monaurally indicated that although latency differences between the hemispheres were in the same direction as those found in the dichotic presentation, they were not significant. No consistent differences existed in peak to peak measures of amplitude. Neville suggested that these results provide support for the hypothesis of asymmetric hemispheric functioning. A study by Galambos, Benson, Smith, Schulman-Galambos, and Oser (1975), employing binaural natural speech syllables and pure tones as stimuli, failed to demonstrate significant differences between left and right auditory AEPs in either amplitude or latency. However, the authors did report a somewhat longer P_3 latency to speech sounds than to tones for the left hemisphere. The inconsistencies in the results of the two studies may be explained by considering the type of task. Galambos et al. used simple speech sounds (e.g., pa, ba), while Neville employed digits and clicks. It is very likely that this type of speech sound, a short simple syllable, would not evoke an asymmetric response, as research has shown (Gazzaniga, 1976; Levy, 1976; Teng, & Sperry, 1973) that both hemispheres can respond equally well to this type of simple speech. It may be, as Neville (1974) suggested,

that a degree of complexity in the cognitive task is necessary in order for an asymmetric AEP to be observed as a correlate of that task.

Also, differences in visual AEPs have been reported for verbal and non-verbal stimuli. Buchsbaum and Fedio (1969) had subjects observe, although not overtly respond to, word, dot, and design stimuli. Results indicated that the latency of the positive peak (190-280 msec.) was shorter for words than for dots and designs in both hemispheres. The latency in the left hemisphere, however, was shorter than the latency in the right hemisphere. The results also indicated that AEPs for words and AEPs for designs were most different in the left hemisphere. The authors felt that this was consistent with the notion that verbal information is processed in that hemisphere. Galin and Ellis (1975) have also reported that asymmetries in the AEP correlate with verbal and spatial tasks. The authors identified two measures of the AEP. Amplitude was measured using an early negative (100-140 msec.)--positive (150-180 msec.) configuration and a later positive (250-280 msec.)--negative (320-350 msec.) configuration. Power was determined by integrating the amplitude over time (100-350 msec.). The right/left ratios of amplitude were higher for verbal than for spatial tasks for both early and late configurations. Similarly, the right/left power ratio was greater for verbal than for spatial tasks for all subjects. Similar results have been reported by Vella, Butler, and Glass (1972). The results of these studies indicates that some correlation exists between the type of task (i.e., verbal or spatial) and specific underlying neural events.

EEG studies: The resting state. EEG research has sought to strengthen the link between task (e.g., verbal or spatial) and asymmetry of underlying

neural activity. However, it has been necessary to determine the extent of non-task dependent asymmetries existing in the EEG and its components, and to determine whether this asymmetry can be reliably correlated with greater activation of either the right or left hemisphere, especially as there has been some suggestion that resting asymmetries may be linked to cerebral dominance (see Appendix B).

A study of the EEG has reported asymmetries in the gross recordings of the brain wave patterns of the two cerebral hemispheres. Butler and Glass (1974) have reported that hemispheric asymmetries in amplitude exist when the total EEG (1-40 Hz) was taken into account. EEG measures obtained during a relaxed situation showed the amplitude from the left hemisphere to be significantly attenuated relative to that from the right hemisphere in right-handed individuals, with a slight tendency (not significant) for a reversal of this effect in left-handed individuals. Butler and Glass have suggested that the total whole band EEG asymmetry can be correlated, to some degree, with handedness.

However, assessments of asymmetries in the 8-13 Hz bandwidth during a resting state have proved inconclusive. Several authors have reported resting asymmetries in the alpha rhythm, such that the amplitude from the left hemisphere was attenuated relative to the right hemisphere, (Doyle, Ornstein, & Galin, 1974; Morgan, McDonald, & McDonald, 1971; Smyk & Darwaj, 1972), while others (Butler & Glass, 1974; Morgan, McDonald, & Hilgard, 1974) have not. An attempt at explaining the inconsistencies in the area have been confounded by the fact that: (a) not all studies defined a resting state in the same manner; (b) electrode placement differed; (c) cloistering of subjects differed, and (d) the sex of

subjects differed.

a. Most of the previous investigators defined a resting state as a relaxed no-task situation. Doyle et al. (1974), however, had subjects attend to their breathing during a resting state. This simple command may have given the task enough of a cognitive dimension to limit its usefulness as a neutral task and thus led to the reported asymmetry in alpha amplitude. At the very least, inclusion of the command rendered the results questionable.

b. Alpha amplitude symmetry varies depending upon electrode placement. Galin and Ornstein (1975) have reported that alpha amplitude was most symmetrical over the occipital areas and least symmetrical over the parietal and temporal areas. Examination of the studies in question indicated that considerable overlap in electrode placement existed in those studies that did and did not report asymmetry. Butler and Glass (1974), Morgan et al. (1971), Morgan et al. (1974) and, Smyk and Darwaj (1972) all used occipital placements. Butler and Glass used an additional central placement and Doyle et al. (1974) employed temporal and parietal placements. Use of temporal and parietal placements would lead to greater asymmetry, thus partially explaining the results reported by Doyle et al. However, electrode placement appeared to be of limited use in explaining the inconsistent results reported in the remaining studies.

c. Butler and Glass (1974) suggested that differences in the cloistering of subjects led to differences in alpha activity during rest. They hypothesized that having the experimenter and subject in the same chamber could have the effect of maintaining a state of readiness in the verbal left hemisphere of the subject, thereby resulting in alpha

asymmetry, whereas, having the subject remain alone would not result in these asymmetries. Pilot studies by these investigators (1974) where subjects were seated either alone or in the presence of an experimenter tended to support the hypothesis. Butler and Glass were the only investigators to place subjects in a separate room. Most of the previous studies (the exception being Smyk and Darwaj (1972) who did not report this detail) placed the experimenter and subject in the same chamber. Of these, some studies reported alpha asymmetry, while others reported alpha symmetry confounding possible interpretation.

d. Symmetry or asymmetry of the resting alpha amplitude may be due to the sex of the subjects used in a study. Davidson, Schwartz, Pugash, and Bromfield (1976) reported that right-handed females exhibited more alpha rhythm asymmetry during rest than did males. Further, both Buffrey and Gray (1972) and Levy (1972; 1976) have suggested, on the basis of reported evidence, that females and males have differences in lateralization of function. These observations suggested that differences in the male-female ratio of the subject population of an experimenter would increase or decrease the likelihood of findings of alpha asymmetry during rest. If there were more females than males in a study, there could be a greater likelihood of reporting resting asymmetries. Since many of the studies did not report the sex of their subjects, it was impossible to determine whether the above hypothesis was valid. However, the mixing of sexes in a study may further lead to a confounding of results.

Due to the serious nature of confounding in the available literature it has been impossible to provide an adequate explanation for the

existing inconsistencies in findings. Further, due to the inconsistencies in the literature, the exact nature of alpha rhythm activity during a resting state remains unclear.

EEG studies: Evidence for task dependent asymmetry. Recent studies have reported a strong correlation between type of task and EEG asymmetry (Doyle et al., 1974; Galin & Ornstein, 1972). Investigators (Butler & Glass, 1974; Doyle et al., 1974; Dumas & Morgan, 1975; Morgan et al., 1971; Morgan et al., 1974) have determined that asymmetries in the alpha band (alpha amplitude, percent-time alpha, and alpha power) provide a sensitive index of the cognitive activity inferred from varying the task demands during an experimental situation.

Galin and Ornstein (1972) first described asymmetry of the EEG during task performance. EEG recordings were taken from the left and right temporal and parietal areas during performance of two verbal tasks (one motor--writing a letter, one non-motor--mentally composing a letter with eyes open and fixated) and two spatial tasks (one motor--memorizing a two-dimensional geometric pattern and then constructing it out of multicolored blocks; one non-motor--viewing a sectioned figure and mentally selecting which of the five assembled figures could be constructed from the sections). The EEG was quantified in terms of power (voltage integrated over time--high amplitude activity will have a higher power density) by integrating the whole band raw signal (1-35 Hz) over one second periods. Asymmetry between homologous leads (e.g., right temporal and left temporal) was expressed as a ratio of right to left power. The average power during each task was calculated and the ratio of the power

values, parietal right/parietal left and temporal right/temporal left, were computed for each task. The ratio of right to left power for both electrode locations was significantly greater on verbal than on spatial tasks for both motor and non-motor tasks. Further, there was no significant difference in power between motor and non-motor verbal tasks or motor and non-motor spatial tasks. The results reflected what appeared to be a task dependent asymmetry in the EEG: during verbal tasks there was relative left hemisphere activation, and consequently, less alpha activity than in the right hemisphere; whereas during spatial tasks there was relative right hemisphere activation, and consequently, less alpha activity than in the left hemisphere. In an elaboration of the previous study, using the same experimental procedure but with additional cognitive tasks, Doyle et al. (1974) reported that EEG lateral asymmetry (expressed as a ratio of right/left power) reliably reflected type of task. Additionally, power spectrum analysis of each component of the EEG (delta, theta, alpha, beta) revealed that the asymmetry was strongest in the alpha band. There was little recorded activity in the delta band. The authors attributed asymmetries in the theta band to motor activity, since these occurred mainly during motor tasks, and asymmetries in the beta band to either spillover from the alpha band or to contamination by muscle artifact. The alpha band, therefore, most reliably reflected a cognitive task-related asymmetry. In a recent study, Galin and Ellis (1975) compared asymmetry in evoked potentials and asymmetry of EEG alpha (again quantified as power) as indices of lateral cognitive processes. The results indicated that both evoked potentials and alpha power were indicative of type of task. However, the authors concluded that alpha power

was more stable and consistently correlated with type of task.

Further evidence of task dependent asymmetry has been reported by McKee, Humphrey, and McAdam (1973). Right-handed male and female subjects were given a series of linguistic tasks scaled (by the experimenters) for difficulty, plus a musical task. Alpha asymmetry was quantified in terms of power, with asymmetry being expressed as a ratio of left to right power. The results indicated that significant task dependent asymmetry occurred for musical as well as linguistic tasks, with ratios of left/right alpha largest for musical tasks and progressively smaller for linguistic tasks.

Recently, evidence for task dependent asymmetry has been reported by investigators using alpha amplitude to assess asymmetry (Butler & Glass, 1974; Morgan et al., 1971; Morgan et al., 1974). Morgan et al. (1971) reported that when subjects were given analytic tasks involving verbal or arithmetic manipulations, there was proportionately less alpha activity in the left hemisphere as compared to the right, than when they were engaged in spatial tasks. These differences in the amplitude of occipital alpha between the left and right hemisphere were significant. Butler and Glass (1974) also reported that alpha amplitude was significantly smaller in the left hemisphere during numeric tasks. Further, Morgan et al. (1974) reported that while alpha amplitude was somewhat depressed in both hemispheres during analytic (verbal and numeric) tasks and during spatial (imaginational) tasks, significantly more of the total alpha activity came from the right hemisphere during the analytic tasks than during the spatial tasks.

Further evidence of task dependent asymmetry was reported

by Dumas and Morgan (1975). In this case, task dependent asymmetry was quantified as percent difference in alpha. The total alpha for each 20 second epoch was calculated for each hemisphere. Lateralized alpha, which was defined as the tendency for more or less alpha to come from each hemisphere as a function of task, was then calculated by means of the equation $\frac{\alpha_R - \alpha_L}{\alpha_R + \alpha_L} \times 100$. Right hemisphere alpha was designated α_R , left hemisphere alpha, α_L . The investigators reported that the laterality scores of the left hemisphere tasks (analytic) differed significantly from the laterality scores of the right hemisphere tasks (spatial), with alpha suppression, relative to the total amount of alpha, in the hemisphere dominant for a particular task. Davidson et al. (1976) also reported task dependent asymmetry quantified in terms of percent difference. The tasks involved whistling a song, singing a song, and talking the lyrics of a song. There was significantly less alpha activity in the left hemisphere during the talk condition than during the whistle and sing conditions.

In sum, the reported evidence has indicated what appears to be a task-dependent asymmetry of the EEG. Further, alpha activity has been shown to most sensitively reflect task-dependent asymmetry, whether that asymmetry is as measured in terms of power, amplitude, or percent difference.

Alpha Asymmetry and Cognitive State: Biofeedback Studies

Recently, investigators employed biofeedback procedures to demonstrate specific asymmetric control with a number of physiological measures. Varni (1975) reported that subjects displayed significantly larger electrodermal responses (GSR) in one hand as compared with the

other during a classical conditioning study. Roberts, Kewman, and MacDonald (1973), employing an auditory feedback paradigm in conjunction with hypnotic trance, successfully trained subjects to differentially control the temperatures in their right and left hands. Steptoe, Mathews, and Johnson (1974) reported that subjects given analogue meter feedback could learn to differentially control the temperature in their earlobes. Further, Schwartz (1972; 1975), Schwartz, Shapiro, and Tursky (1971), and Shapiro, Schwartz, and Tursky (1972), demonstrated that responses within a single system (cardiovascular) could be differentially controlled. Subjects provided with biofeedback were able to produce simultaneous increases in heart rate and decreases in blood pressure and vice-versa. This kind of research suggested that asymmetric control of physiological responses was possible, and that biofeedback methods provided the necessary means of achieving that control.

Biofeedback procedures also have been employed to elucidate the relationship among recordable neural activity, hemispheric differences, and cognitive state. To ascertain, in part, whether localized control of alpha rhythm activity was possible, researchers (Davidson et al, 1976; Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977; O'Malley & Connors, 1972; Peper, 1971; Peper, 1972; Schwartz, Davidson, & Pugash, 1976) have investigated whether individuals could be trained to produce specific patterns of alpha asymmetry. Moreover, certain investigators (Davidson et al, 1976; Schwartz et al, 1976) have attempted to ascertain whether specific trained patterns of alpha asymmetry could be correlated with particular modes of cognition. However, as various types of biofeedback methods have been used by these investigators, a discussion of the methods employed is necessary.

Biofeedback methods. Biofeedback information of alpha activity has been provided either via the visual system (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) or via the auditory system (Davidson et al., 1976; O'Malley & Connors, 1972; Peper, 1971; 1972; Schwartz et al., 1976). Investigators employing visual feedback methods most often have used a slide that was turned on by an alpha event and turned off by a no-alpha event. Investigators employing auditory feedback generally have used a tone that was triggered on by bursts of alpha activity and turned off by EEG activity other than alpha.

Feedback information has been provided in either a binary or proportional form and there exists some controversy as to which form has been most effective (see Appendix C). A binary feedback signal provides present/absent information only. Several investigators of alpha asymmetry training have employed a binary feedback signal (Davidson et al., 1976; Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977; O'Malley & Connors, 1972; Peper, 1971; Schwartz et al., 1976). A proportional feedback signal provides information about quantifiable ongoing events in the specified activity. Peper (1972) has been the only investigator to employ a proportional feedback signal during alpha asymmetry training.

In addition to differences in the sensory modality employed, and in the amount of information contained in the feedback signal, biofeedback studies of alpha asymmetry can be further divided into three distinct groups depending on the kind of EEG information subjects received:

(a) Peper (1972) used a method whereby independent feedback was provided about each hemisphere. Subjects heard two tones, a high tone and

a low tone, and each tone provided proportional feedback information about the alpha activity of one hemisphere. The enhancement of one tone (indicating increases of alpha activity in that hemisphere) coupled with the simultaneous suppression of the second tone (indicating decreases of alpha activity in that hemisphere) was indicative of asymmetry in alpha activity across the hemispheres. (b) Several investigators (Davidson et al., 1976; O'Malley & Connors, 1972; Peper, 1971; Schwartz et al., 1976) used a method referred to as pattern biofeedback (cf. Davidson et al., 1976). In this case, a single tone providing binary information occurred only when one hemisphere generated alpha activity and the other simultaneously generated no-alpha activity, thus reinforcing a pattern of alpha asymmetry across the hemispheres. (c) Mulholland and associates (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) used a method whereby binary visual feedback was provided about the alpha activity of one hemisphere only (contingent hemisphere), while the EEG activity of both hemispheres was monitored. A difference in the alpha activity of the contingent hemisphere from that of the noncontingent hemisphere would lead to asymmetry across the hemispheres.

As can be seen, biofeedback studies of alpha asymmetry can be grouped according to sense modality employed, amount of information provided by the feedback signal, and kind of EEG information provided by the signal. All methods of biofeedback have achieved some measure of success in alpha asymmetry training.

Feedback studies. Some evidence for asymmetric control of alpha activity or localized control of the alpha rhythm was reported by Peper

(1972). Feedback information was independently provided for each hemisphere by means of one low and one high frequency tone. The study consisted of two sessions with either four or six feedback trials a session. Subjects were instructed to enhance one tone while simultaneously suppressing the other for one trial, reverse the procedure for the second trial, and so on. Subjects, therefore, had either four or six trials in total to learn to both enhance and suppress the central-temporal alpha activity in the appropriate hemisphere. Of eight subjects, only one was able to control the alpha activity successfully. This subject was able to increase and suppress the percent-time alpha activity of only the right hemisphere. The data for the other seven subjects were not reported. The results of the study indicated that localized control of the alpha rhythm was possible. However, the exploratory nature of the study, coupled with incomplete data, makes interpretation of the findings difficult. It is possible, however, that the limited success of the study may have been due to the overwhelming amount of EEG information provided, rendering the task overly complex. Subjects were receiving two feedback signals and consequently had to attend to and try to control two separate events simultaneously. Coupled with an extremely short training period, this simultaneous control might have been too difficult a task for most subjects.

Decreasing the complexity of the task by reducing the amount of information has proved more effective in training alpha asymmetry. Several studies employing pattern biofeedback have been conducted. One of the earliest studies was done by Peper (1971). He employed a binary feedback tone which was activated during the asymmetry condition by

an alpha event in the occiput of one hemisphere concomitant with a no-alpha event in the occiput of the other hemisphere and during the symmetry condition by alpha events in both hemispheres. Two of six subjects were able to successfully control asymmetry, producing 31 seconds of asymmetry out of a possible 120 seconds on the asymmetry trial, and only three seconds of asymmetry on the alpha symmetry trial. O'Malley and Connors (1972) used a similar feedback method. The single subject was able to significantly increase total alpha time in the left hemisphere, while significantly decreasing alpha time in the right hemisphere. The degree of control over alpha activity reported by O'Malley and Connors was much greater than that reported by Peper. Comparison of the studies indicated a number of factors that contributed to that greater control. First, the O'Malley and Connors' study lasted for five sessions, the Peper study for one. Second, the feedback tone in the O'Malley and Connors' study was contingent on an alpha event in the left hemisphere coupled with a no-alpha event on the right hemisphere, while the feedback tone in the Peper study was contingent on alpha asymmetry independent of hemisphere. Third, feedback was provided only for an asymmetric response in the O'Malley and Connors' study, while in the Peper study, the feedback signal indicated an asymmetric response for half the trials and a symmetric response for the remaining half. It appears that while pattern biofeedback may be an effective means of training alpha asymmetry, an adequate number of training sessions plus feedback provided consistently for asymmetric activity are necessary for successful training.

Further, evidence of asymmetric control of alpha activity using the pattern biofeedback method has been reported by Davidson et al. (1976). The results of this study were particularly important in that the authors sought not only to determine the effect of sex differences on control of alpha asymmetry, but also the ability of subjects to control three different patterns of alpha activity. The procedure was such that twenty right-handed subjects, ten males and ten females, experienced three blocks of trials. Each block consisted of 12 one-minute trials, of which nine were feedback trials with a rest trial after every three feedback trials. Each block of trials corresponded to one of the three EEG patterns, right alpha ($R\alpha$) off-left alpha ($L\alpha$) off, $R\alpha$ on-- $L\alpha$ off, $R\alpha$ off-- $L\alpha$ on. For the $R\alpha$ off-- $L\alpha$ off condition, subjects were instructed to keep the binary feedback tone off as much as possible. For the other conditions, they were instructed to keep the tone on as much as possible. The results confirmed reports by other investigators that subjects were able to exercise significant control over the alpha activity, be it a pattern of integration (e.g., $R\alpha$ off-- $L\alpha$ off) or a pattern of differentiation (e.g., $R\alpha$ on-- $L\alpha$ off). The results further indicated that males and females were not equally adept at controlling patterns of differentiation. While both males and females were able to produce significant amounts of asymmetry in the $R\alpha$ on-- $L\alpha$ off condition, only females generated significant amounts of asymmetry in the $R\alpha$ off-- $L\alpha$ on condition. These data suggest that right-handed males, at least, cannot demonstrate similar or equal control over the alpha activity of the right and left hemispheres when that control is elicited via patterns of differentiation.

Recently, Schwartz et al. (1976) reported on additional data collected during the Davidson et al. (1976) study. Overall, subjects spent more time in the R α on --L α off condition than in the R α off--L α on condition. Also, subjects produced significantly more R α on--L α off activity during that differentiation condition than during rest, while there was no significant difference in the amount of R α off --L α off activity generated during training as compared with rest. These data suggested that the R α on --L α off pattern might be easier to generate and maintain than the R α off--L α on pattern. Schwartz et al. (1976) also studied the cognitive state of their subjects. Earlier reports from a study by Peper (1972) suggested that specific patterns of cortical asymmetry were associated with specific cognitions. Schwartz et al. (1976) found that subjects' reports, collected after each block of feedback trials, showed a significant correlation between the trained pattern of asymmetry and cognitive activity. For example, during the R α on--L α off block, subjects reported significantly more visual activity than during the R α off --L α on block. These data are consistent with the evidence for asymmetry of cognitive functions (Dimond & Beaumont, 1976), as well as the evidence for task dependent asymmetry (Doyle et al., 1974).

Although pattern biofeedback appears effective for learning self-control of patterns of asymmetry, the method does not lend itself to the study of specific hemispheric differences that may occur in the learning of differential control of alpha activity. Pattern biofeedback requires simultaneous modification of the EEG activity of both hemispheres, since feedback is provided only when a specific alpha/no-alpha pattern occurs across the hemispheres. Its use, therefore, is limited to investigations

where the simultaneous modification of the activity of both hemispheres is of interest. The method cannot be used to answer such questions as: Using the same training procedure, can subjects control the alpha activity of each hemisphere with equal facility? Does modifying the alpha activity of a hemisphere affect the alpha activity of the contralateral hemisphere? Does the bilateral EEG asymmetry generated during self-control of left hemisphere alpha mirror the bilateral EEG asymmetry generated during self-control of right hemisphere alpha? These kinds of questions can be answered by recording the EEG activity of both hemispheres while providing feedback contingent on the activity of only one hemisphere.

In a series of studies Mulholland and associates (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) reported that visual feedback contingent on the alpha activity of one hemisphere increased the control of alpha and no-alpha events in that hemisphere relative to the non-contingent hemisphere. Limited comparisons between the left contingent and right contingent hemispheres indicated that control of alpha events was slightly better on the right (Mulholland & Eberlin, 1977). Differences in bilateral EEG asymmetry were not examined. The studies do provide evidence that localized control of alpha activity can occur when feedback is contingent on the alpha activity of only one hemisphere.

Purpose of Study

Examination of the functioning of the hemispheres has established a strong relationship between lateralization of cognitive functioning and hemisphere (Dimond & Beaumont, 1976). Moreover, a relationship

between specific cognitive activity and patterns of alpha asymmetry has been established, particularly in the case of task-dependent asymmetry (Doyle et al., 1974; Morgan et al., 1971; 1974). Further, studies using various biofeedback techniques have demonstrated that patterns of alpha asymmetry can be conditioned (Davidson et al., 1976; O'Malley & Connors, 1972; Peper, 1971; 1972; Schwartz et al., 1976). In addition, Schwartz et al., (1976) have reported correlations between particular patterns of alpha asymmetry and subjective reports of specific cognitive activity. These reports have been consistent with evidence from studies of task-dependent asymmetry. Finally, studies (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) have indicated that control of alpha activity can be localized to one hemisphere. Thus a correlative link exists among hemisphere, lateralization of cognitive function, and specific patterns of alpha asymmetry.

Such evidence coupled with the findings of anatomical asymmetries between the hemispheres (Wada, Clark, & Hamm, 1975) has prompted suggestions that the patterning of neural activity underlies the emergence of cognitive and subjective experience (Schwartz et al., 1976; Sperry, 1969). Furthermore Semmes (1968) has suggested that hemispheric differences in processing could underly lateralization of cognitive functioning. Biofeedback research has tended to concentrate on self-regulation of specific patterns of neural activity and the relationship to subjective experience. While this area of research has been important, little has been done to determine how differences in cognitive mode are related to differences in hemispheric processing. One reason for this may be that the pattern biofeedback method cannot easily be used to investigate this area as the method involves the simultaneous modification of both hemispheres.

Hemispheric asymmetries, therefore, are built into the method. However, the self-regulation approach as a general strategy is useful. It provides the framework whereby a researcher may isolate and study the processing of each hemisphere and thus determine how these combine to produce particular neural patterns and cognitive events. The biofeedback approach utilized by Mulholland and associates (e.g., Eberlin & Mulholland, 1976) has provided an adequate method for studying the relationship among the alpha component of the EEG, hemispheric inter-relationship, and associated subjective states.

Previously, it was noted that the biofeedback method, which involves recording the EEG activity of both hemispheres while providing feedback contingent on the activity of only one hemisphere (e.g., Eberlin & Mulholland, 1976), does indeed lead to hemispheric differences in alpha (alpha asymmetry). Unfortunately, these studies (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) differed from previous studies, not only in the biofeedback method employed, but also in that visual rather than auditory feedback was used. Thus, direct comparisons across studies may be inappropriate. One further difficulty, applicable to all previous biofeedback studies in this area, has been that the studies have been designed so that each subject participated in the different feedback conditions within the study. That is, at one point in time subjects would receive feedback contingent on increases of alpha activity in a particular hemisphere, while at another time the same subjects would receive either feedback contingent on suppression of alpha activity, or no feedback at all, for that same hemisphere. These within-subjects designs tend to complicate further data interpretations. This

would be especially true in a study employing feedback that was contingent on the alpha activity of only one hemisphere (Eberlin & Mulholland, 1976). The noncontingent hemisphere could at some point received feedback while generating alpha. Given the nature of hemispheric interconnections these incidences might tend to increase over trials in some non-random fashion so that, when the previously noncontingent hemisphere becomes contingent, learning relevant to the task could have already occurred. The effect of this previous learning might be either to increase the likelihood of success at the task, or, if sufficient increases in alpha had occurred during the noncontingent state, decrease the apparent success at the task by reducing the amount of change possible. The meaningfulness of the results, therefore, would be somewhat obscured. A design where observations were made both between and within groups could circumvent this problem.

This study employed a method where feedback was contingent on the alpha activity of one hemisphere. This method allowed for the evaluation of the activity of each hemisphere the contribution of each hemisphere to a pattern of alpha asymmetry, the patterns of activity across the hemispheres during feedback, and associated subjective states. To this end, two groups of right-handed male subjects each experienced proportional auditory feedback. One group received feedback contingent on the alpha activity of the right hemisphere; the second group, feedback contingent on the alpha activity of the left hemisphere. The major questions were: (a) Would the contingency manipulation be effective in producing patterns of alpha asymmetry? (b) Would self-control over alpha activity be achieved with equal facility by each hemisphere? (c) Would the EEG asymmetry generated during self-control of left hemisphere alpha mirror

the EEG asymmetry generated during self-control of right hemisphere alpha? (d) Would this type of feedback training be accompanied by predictable cognitive concomitants; i.e., would subjective reports from the right-trained group differ from those of the left-trained group?

Thus, an attempt was made to investigate the relationship between hemispheric differences in processing (self-control of alpha enhancement) and cognitive activity (subjective reports). Further, it was expected that the experimental design employed would enable comparison of results between within-group and between groups observations.

Subjects

Thirty-two right-handed male students, solicited from the subject pool at The University of Manitoba, received experimental credit for their participation in the study. All subjects were naive to the experimental situation and were non-meditators.² All were physically healthy and had no record of any neurological disorder. None of the participants reported taking drugs of any type. Two subjects were eliminated from participation in the study because of excessive eye movement during the training activity.

Apparatus and Recording Procedure

Occipital EEGs were recorded bilaterally from O_1 and O_2 according to the 10-20 system (Jasper, 1958). Each electrode was referenced to a linked-ear arrangement (E_z). The EEG was recorded with Grass silver cup electrodes and resistance between the electrode pairs ($O_1 - E_z$; $O_2 - E_z$) was under 5000 OHMS. Eye movements were recorded via miniature Beckman electrodes placed above and below the right eye. A Beckman electrode placed on the right arm served as ground.

All measures were recorded on a Grass Model 6 electroencephalograph and ink writing oscillograph (see Figure 1). Two channels of the oscillograph displayed the raw EEG. Each EEG signal was filtered for 8-13 Hz activity by separate band pass filters and the filtered records were displayed on two additional oscillograph channels. Variable amplitude

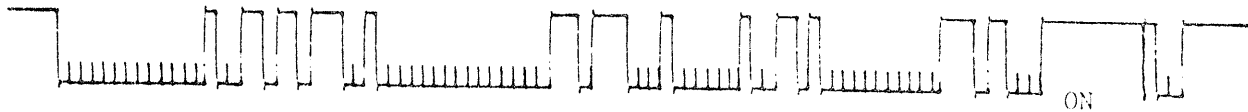
²Research has indicated that meditation has some effect on the alpha rhythm frequency and amplitude. For this reason, meditators were excluded from the subject pool. (Kamiya, 1969).

Figure Caption

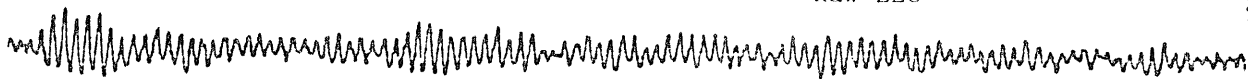
Figure 1. Illustrative tracing of raw and filtered electrocephalogram (EEG) and electro-oculogram (EOG) from an individual subject. Feedback was contingent on right hemisphere activity. The filters were triggered by an alpha wave above 15 μ v in intensity. Paper speed was 15mm/sec.

Right Contingent Hemisphere

Filtered EEG OFF



Raw EEG

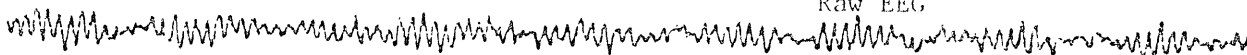


Left Noncontingent Hemisphere

Filtered EEG OFF



Raw EEG

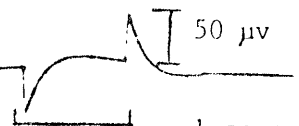


EOG



50 μ v

1 second



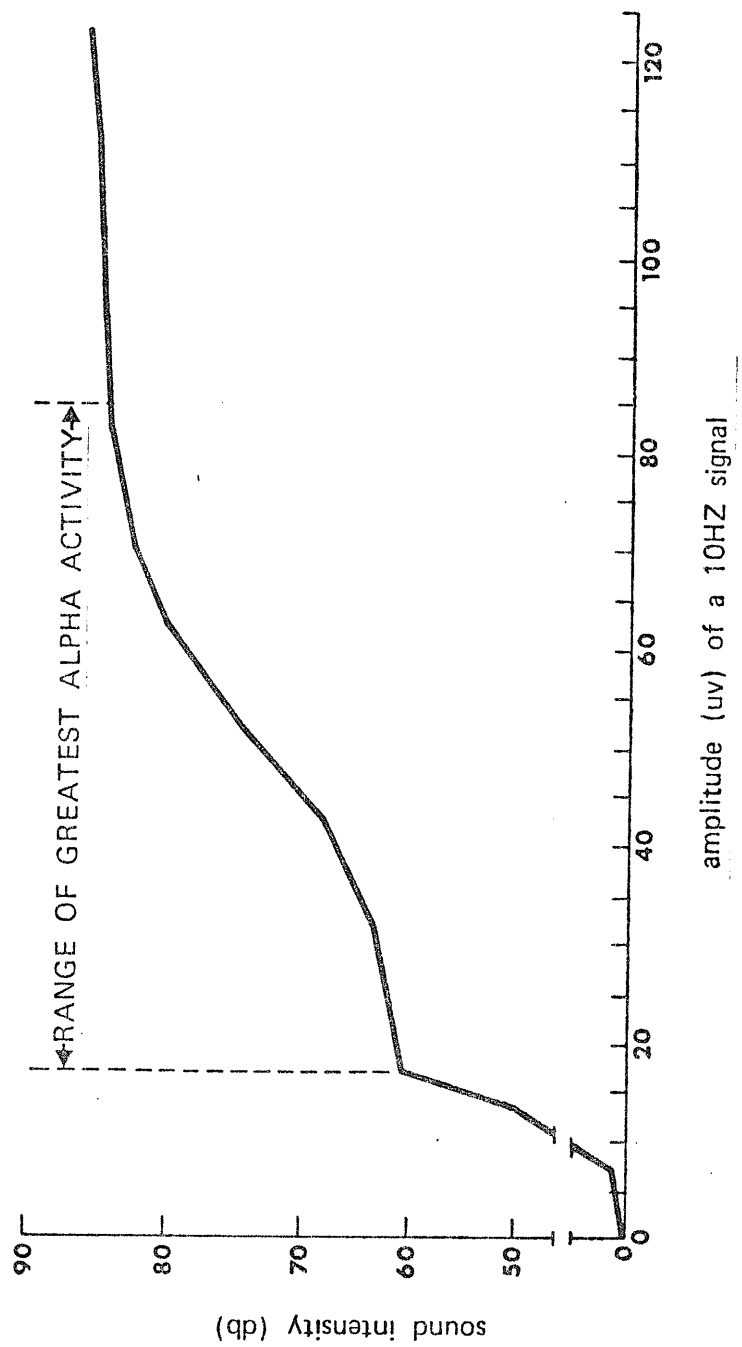
detectors on the band pass filters were set so that a signal had to be in excess of 15 μ V to be counted. Two Hunter Klockcounters (Model 120A), each connected to a band pass filter, accumulated criterion alpha time. One of the two band pass filters, connected to a Hewlett-Packard wide range oscillator (Model H20-200CD) delivered auditory feedback to the subject via a loudspeaker. The feedback tone (400 Hz) increased in intensity as the alpha amplitude increased (see Figure 2). It should be noted that for any one subject, only one hemisphere was connected to the feedback path. Eye movements were recorded on a fifth channel and were visually monitored.

Procedure

All subjects participated in two experimental sessions. The sessions were held on consecutive days and subjects were scheduled for the same time period on each day. At their initial appearance, subjects were randomly assigned to one of two groups; a group where feedback was contingent upon the alpha activity of the right hemisphere, or a group where feedback was contingent upon the alpha activity of the left hemisphere. Subjects were given the Lateral Dominance subtest from the Halstead Neuropsychological Test Battery (see Appendix D) to determine hand and eye dominance, and were then told that they would be participating in a study of brainwave activity. After the electrodes were in place, subjects were given standardized instructions to read (see Appendix E). They were then seated in a radio-frequency shielded chamber and a speaker was placed 1.8 meters in front of them. The overhead lights were extinguished, and two 20 watt red bulbs situated behind the chair provided ambient illumination. Subjects were again cautioned to sit as quietly as possible

Figure Caption

Figure 2. Sound intensity of a 400 Hz. auditory tone as a function of variation in the amplitude of a constant 10 Hz. electrical signal (Exact, Model 126 VCF/Sweep Generator) as measured at the speaker face by a Bouel and Kjael precision sound level meter (Type 2203).



throughout the experiment and to remain still during tone-on trials.

Further communication with the subject (i.e., type of trial) was conducted over an intercom system adjoining the two rooms. Subjects were instructed to keep their eyes open throughout the experiment.

The procedure for both sessions was identical. Each session began with a 5-minute adaptation period. During this time the equipment was calibrated. Following this, the feedback tone was turned on for two minutes to eliminate startle effects of the subject to the tone before the feedback trials began. Alpha baselines were then collected for two discrete one-minute periods.

The feedback phase consisted of four blocks of biofeedback training, with each block composed of four one-minute feedback trials followed by a one-minute nonfeedback rest trial. The amount of alpha activity from each hemisphere (i.e., contingent and noncontingent) during each of the one-minute trials was accumulated by the Klockcounters and recorded by the experimenter, who then reset the Klockcounters for the next trial. Subjects were informed via a beep of the intercom as to whether the coming trial would be tone-on (feedback), or tone-off (nonfeedback rest).

At the end of the second session, subjects were given the Cognitive Strategies Questionnaire which asked "To what extent would you say your strategy for turning on the tone involved the following kinds of thought?" (Schwartz et al., 1976). They were required to circle a number from 1 (not at all) to 7 (nearly exclusively) which corresponded to their level of involvement with each of the following categories: (a) verbal, (b) numerical, (c) visual, (d) musical, (e) emotional, (f) thinking nothing, (see Appendix F). Subjects were then debriefed.

Data Analysis

Time spent in alpha was quantified separately for each hemisphere. Each time score represented the number of seconds of alpha activity during a 60-second trial period. For the between groups analyses, measures of alpha laterality were calculated. A laterality score reflected the difference in alpha activity between the hemispheres. Each laterality score was composed of an alpha time score for the right hemisphere and a simultaneous alpha time score for the contralateral hemisphere. In order to facilitate between groups analyses, two different measures of alpha laterality were calculated. One laterality measure, labelled C-laterality (contingency) was used to test for group differences resulting from the contingency manipulation. The formula for the C-laterality score was $\frac{(RH\alpha - LH\alpha)}{(RH\alpha + LH\alpha)} \times 100$ (after Morgan et al., 1972). $RH\alpha$ was the alpha time score from the right hemisphere and $LH\alpha$ was the simultaneous alpha time score from the left hemisphere. A positive score would indicate that a greater percentage of lateralized alpha activity was generated by the right hemisphere, whereas a negative score would indicate that a greater percentage of lateralized alpha was generated by the left hemisphere. (If the contingency manipulation was effective, then the C-laterality scores of the right trained group should be positive and the C-laterality scores of the left trained group negative). The second laterality measure, labelled H-laterality (hemispheric reactivity), was used to test for group differences due to differences in the reactivity of the trained hemispheres to the feedback task. The formula for the H-laterality score was $\frac{(CH\alpha - NCH\alpha)}{(CH\alpha + NCH\alpha)} \times 100$, $CH\alpha$ was the alpha time score of the contingent (trained) hemisphere and $NCH\alpha$ was the simultaneous alpha time score of the contralateral noncontingent (untrained) hemisphere. A positive laterality score would indicate that

a greater percentage of lateralized alpha activity was generated by the contingent (trained) hemispheres, whereas a negative score would indicate that a greater percentage of lateralized alpha activity was generated by the noncontingent hemispheres.

In order to assess the effectiveness of the contingency manipulation, a between groups repeated measures analysis of variance was computed with C-laterality scores during feedback trials as the dependent measure. The analysis was, therefore, a $2(x\ 2\ x\ 4\ x\ 4)$ ANOVA where the between groups factor was contingency (right contingency group, left contingency group) and the within group factors were sessions (day 1, day 2); trial blocks (1, 2, 3, 4) and feedback trials (1, 2, 3, 4). To determine whether contingency differentiated the groups during nonfeedback trials (baseline and nonfeedback rest), a $2(x\ 2\ x\ 5)$ repeated measures ANOVA was computed using C-laterality scores. The between groups factor was contingency (right contingent group, left contingent group) and the within group factors were sessions (day 1, day 2), nonfeedback trials (B, 1, 2, 3, 4).

In order to assess whether the hemispheres reacted differently to the feedback task and to determine whether that effectively differentiated the right and left trained groups, a between groups ANOVA was computed with H-laterality scores during feedback trials as the dependent measure. The analysis was, therefore, a $2(x\ 2\ x\ 4\ x\ 4)$ ANOVA, where the between groups factor was hemisphere trained (either right hemisphere or left hemisphere trained) and the within group factors were sessions (day 1, day 2), trial blocks (1, 2, 3, 4), and feedback trials (1, 2, 3, 4). To determine whether hemispheres reacted differently

during nonfeedback trials (baseline and nonfeedback rest), and to assess whether that differentiated the groups, a $2(x\ 2\ x\ 5)$ repeated measures ANOVA was computed using H-laterality scores. The between groups factor was hemisphere trained (either right hemisphere or left hemisphere trained) and the within group factors were sessions (day 1, day 2), and nonfeedback trials (B, 1, 2, 3, 4).

In order to determine whether training was effective in differentiating contingent from noncontingent same-sided hemispheres, e.g., whether the alpha-time scores of the left contingent and noncontingent hemispheres differed, two between groups repeated measures ANOVAs were computed with alpha time scores during feedback trials as the dependent measure. Each analysis was a $2(x\ 2\ x\ 4\ x\ 4)$ ANOVA. In both ANOVAs the between groups factor was contingency (either right hemisphere contingent, right hemisphere noncontingent, or left hemisphere contingent, left hemisphere noncontingent). The within group factors for both ANOVAs were sessions (day 1, day 2); trial blocks (1, 2, 3, 4) and feedback trials (1, 2, 3, 4). Additionally, to determine whether training differentiated contingent from noncontingent same-sided hemispheres during nonfeedback trials (baseline and nonfeedback rest), two further repeated measures ANOVAs were computed using alpha time scores. Each analyses was a $2(x\ 2\ x\ 5)$ ANOVA. In both ANOVAs the between groups factor was contingency (either right hemisphere contingent, right hemisphere noncontingent, or left hemisphere contingent, left hemisphere noncontingent). The within group factors for both ANOVAs were sessions (day 1, day 2) and nonfeedback trials (B, 1, 2, 3, 4).

To determine whether initial differences existed prior to the

commencement of feedback training, several independent sample t-tests were computed using the final 60 seconds baseline activity prior to the commencement of the first training trial. To determine whether contingency differentiated groups prior to the commencement of training a t-test was computed on the baseline of C-laterality scores. To assess the effect of hemisphere reactivity on group differences prior to the commencement of training, a t-test was computed on the baseline of H-laterality scores. Finally, to determine whether the contingent and noncontingent same-sided hemispheres differed prior to the commencement of training, a t-test was computed between the baseline alpha time scores of the contingent and noncontingent right hemispheres, and between the baseline alpha time scores of the contingent and noncontingent left hemispheres.

To determine whether feedback trials differed significantly from nonfeedback rest trials, a priori correlated t-tests were performed comparing feedback trials to nonfeedback trials. These tests were conducted for each hemisphere and each contingency condition for sessions 1 and 2.

To determine whether a relationship existed between cognitive strategy reports and contingency, a Hotellings T^2 was computed on the six levels of the Cognitive Strategies Questionnaire with contingency as the between groups factor. Finally, an independent sample t-test for group differences was computed on the scores of the lateral dominance subtest.

The EOG records were visually scanned. Subjects whose records indicated either continuous vigorous EOG activity, or numerous epochs where EEG records were contaminated by EOG activity, were eliminated from the study. This occurred in two cases.

Results

In order to present the results as clearly as possible, the findings will be presented in three sections. The initial section will deal with the two laterality scores, C-laterality and H-laterality. The middle section will deal with specific between group differences in alpha time scores, that is, the contingent left hemisphere compared with the noncontingent left hemisphere, the contingent right hemisphere compared with the noncontingent right hemisphere. The final section will deal with the analyses of the lateral dominance subtest and the Cognitive Strategies Questionnaire.

Contingency Manipulation: Group Differences

Figure 3 illustrates the effect of the contingency manipulation on the right and left trained groups during feedback trials. As expected, for the right trained group all C-laterality scores were positive, while for the left trained group most C-laterality scores were negative. Figure 4 illustrates the same effect collapsed across trials. From the figure it appears likely that the contingency manipulation affected C-laterality scores and that contingency also interacted with blocks. The means of the right trained group tend to become slightly more positive, while the means of the left trained group tend to become more negative. It also appears that the slopes of the right and left trained groups are linear.

In order to assess the effectiveness of the contingency manipulation during feedback trials, a between groups repeated measures ANOVA on the C-laterality scores was performed and is presented in Appendix G. The

Figure Caption

Figure 3. C-laterality mean scores for the right trained and left trained groups for sessions one and two. Each score represents a measure of alpha laterality during a 60 second feedback trial.

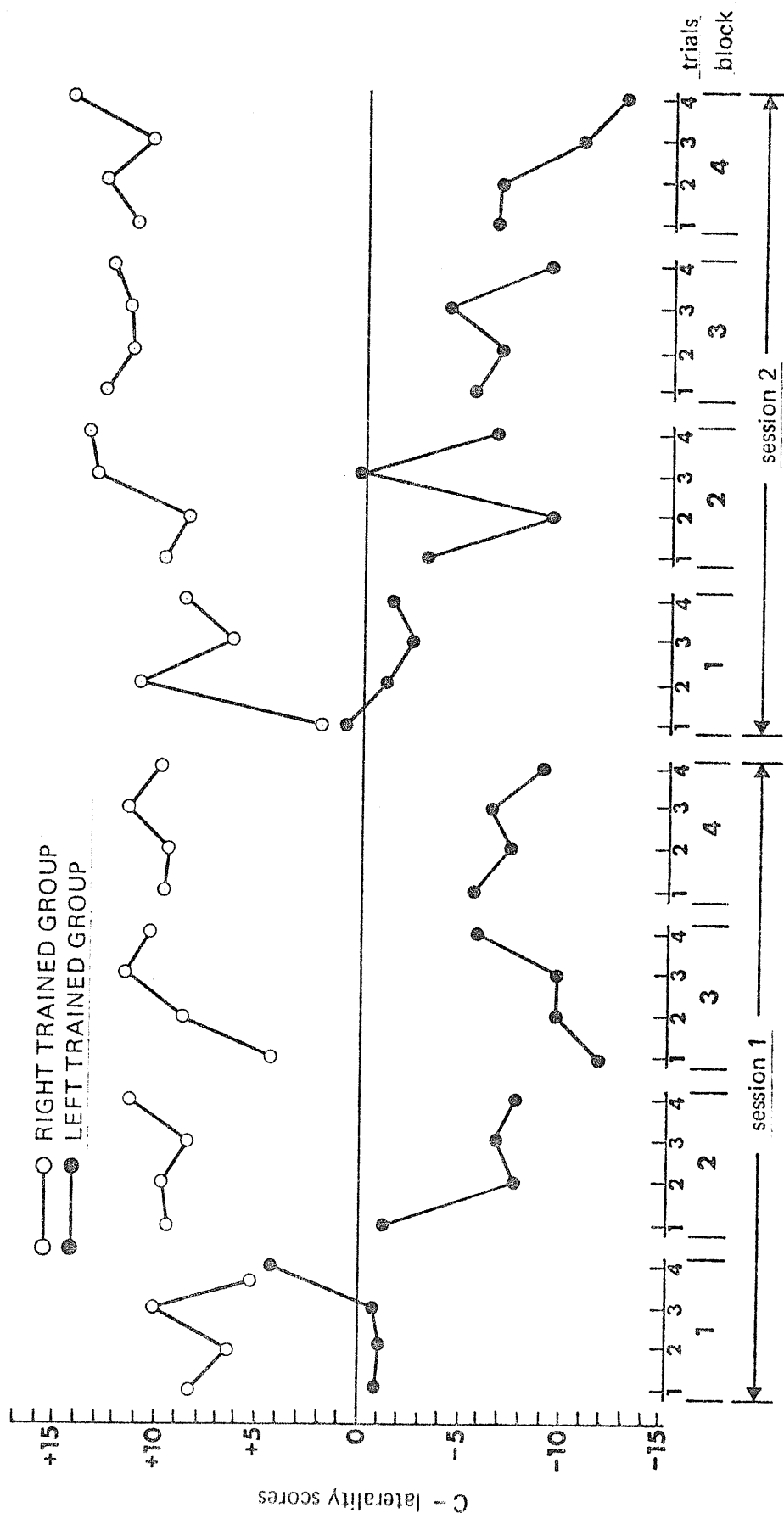
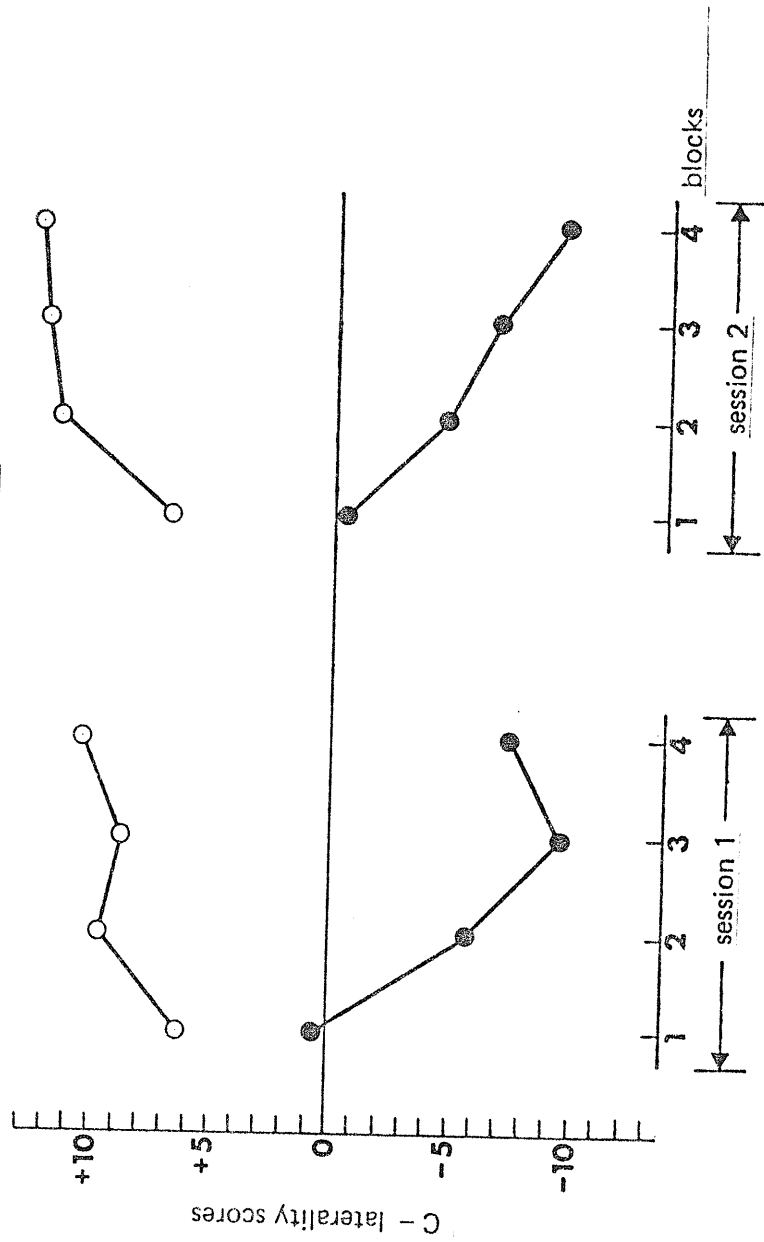


Figure Caption

Figure 4. C-laterality block means for the right trained and left trained groups for sessions one and two. Each mean is based on four feedback trial scores.

○ RIGHT TRAINED GROUP
● LEFT TRAINED GROUP



between groups factor was contingency (right contingency group, left contingency group) and the within group factors were sessions, blocks, and feedback trials. The within group effects were tested via the Geisser-Greenhouse procedure because the traditional repeated measures F is a very liberal test (Kirk, 1968). The results indicated a significant main effect of contingency, $F(1, 28) = 39.000, p < .001$; the left trained and right trained groups differed significantly as a result of the contingency manipulation. The within group main effects of sessions, blocks, and trials were not significant. However, there was a significant contingency by blocks interaction, $F(1, 28) = 9.97, p < .01$, indicating that blocks differed between groups as a function of the contingency manipulation. Finally, a trend analysis confirmed the observation from Figure 4 of a significant linear component for the blocks by contingency interaction, $F(1, 28) = 15.57866, p < .001$.

Table 1 presents the means of the C-laterality scores for the right and left trained groups during nonfeedback trials. The means illustrate that the C-laterality scores for the right trained group are consistently positive, while those of the left trained group fluctuate from positive to negative. It should be noted that the first mean of each session corresponds to a prefeedback baseline trial, the remaining means correspond to nonfeedback rest trials.

In order to be certain that the contingency manipulation significantly differentiated groups during feedback, an independent sample t -test on the prefeedback C-laterality baseline means (right trained group = 5.54260; left trained group = 0.63721) prior to session one

Table 1

C-laterality means for the left trained and the right trained groups for sessions one and two for nonfeedback trials

Session	Trial	Means	
		Left Trained Group	Right Trained Group
1	1	0.63721	5.54260
1	2	-1.82568	1.12548
1	3	0.05726	5.36836
1	4	-2.06977	3.36027
1	5	-2.07190	1.43860
2	1	2.24616	2.96021
2	2	3.15762	3.54520
2	3	-1.76342	9.76460
2	4	1.09447	5.31139
2	5	-3.80144	5.30008
		N = 15	N = 15



was calculated and found to be nonsignificant, $t(28) = 1.24$, $p = .22$.

To assess the effectiveness of the contingency manipulation during nonfeedback trials, a between groups repeated measures ANOVA was computed on the C-laterality scores and is presented in Appendix H. The between groups factor was contingency (right contingency group, left contingency group) and the within group factors were sessions and nonfeedback trials (baseline and 4 nonfeedback rest trials). The Geisser-Greenhouse procedure was employed to test the within group effects. The results indicated a significant main effect of contingency, $F(1, 28) = 7.80$, $p < .05$, demonstrating that the contingency manipulation differentiated groups. There were no other significant results.

Hemispheric Reactivity: Group Differences

Figure 5 illustrates the effect of hemispheric reactivity on the right and left trained groups during feedback trials. For the right trained group all the H-laterality scores were positive, while for the left trained group most of the H-laterality scores were positive. Figure 6 illustrates the same data collapsed across trials. From the figure it appears likely that the H-laterality scores of each group responded similarly over blocks; the means of both groups tend to become more positive. It also appears that the slopes of the right and left trained groups are linear.

In order to assess whether differences in the reactivity of the hemispheres to feedback differentiated the right trained from the left trained group during feedback trials, a between groups repeated measures ANOVA on the H-laterality scores was computed and is presented in

Figure Caption

Figure 5. H-laterality mean scores for the right trained and left trained groups for sessions one and two. Each score represents a measure of alpha laterality during a 60 second feedback trial.

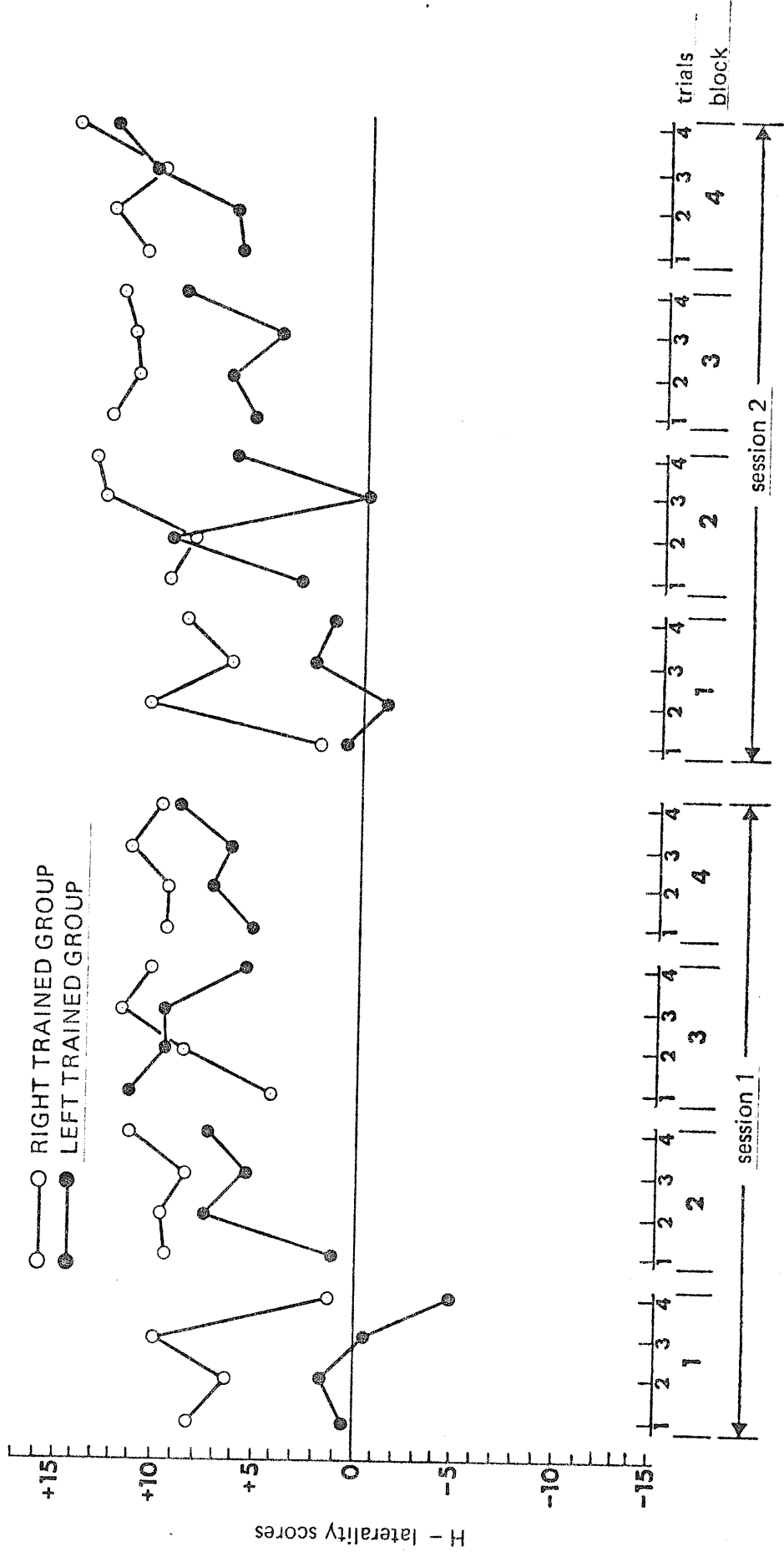
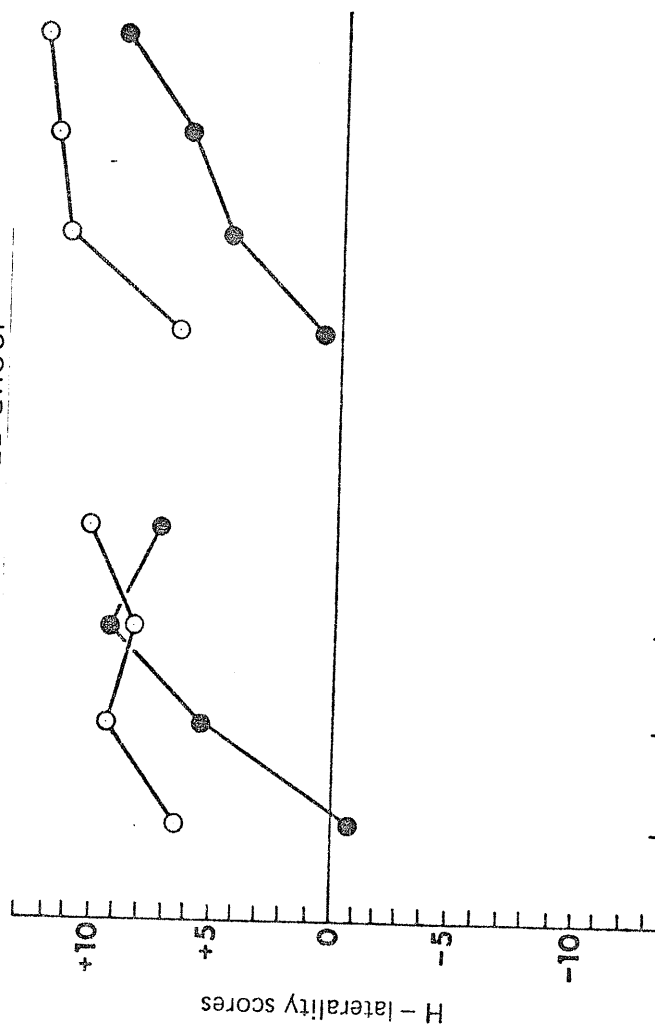


Figure Caption

Figure 6. H-laterality block means for the right trained and left trained groups for sessions one and two. Each mean is based on four feedback trial scores.

○ RIGHT TRAINED GROUP
● LEFT TRAINED GROUP



1 2 3 4
session 1

1 2 3 4
session 2
blocks

Appendix I. The between groups factor was hemisphere trained (right trained group, left trained group) and the within group factors were sessions, blocks, and trials. Again, the Geisser-Greenhouse procedure was used to test the within group effects.

The results indicated that the main effect of hemisphere trained was not significant, $F(1, 28) = 3.37, p < .07$. The within groups main effect of blocks was significant, $F(1, 28) = 9.97, p < .01$. A trend analysis confirmed the observation from Figure 6 of a significant linear component for blocks, $F(1, 28) = 16.88, p < .001$. No other effects were significant.

Table 2 presents the means of the H-laterality scores for the right and left trained groups during nonfeedback trials. The means illustrate that the H-laterality scores of the right trained group are consistently positive, while those of the left trained group fluctuate from positive to negative. Again, note that the first mean of each session corresponds to the prefeedback baseline trials and that the remaining means correspond to nonfeedback rest trials.

To ascertain whether hemispheric activity differentiated groups prior to feedback, an independent sample t -test on the prefeedback H-laterality baseline means (right trained group = 5.54260, left trained group = 0.63721) prior to session one was calculated and found to be nonsignificant, $t(28) = 1.56, p = .131$. To determine whether differences in hemispheric activity differentiated the right from the left trained group during nonfeedback trials, a between groups repeated measures ANOVA was computed on the H-laterality scores

Table 2

H-laterality means for the left trained and right trained groups for sessions one and two for nonfeedback trials

Session	Trial	Means	
		Left Trained Group	Right Trained Group
1	1	-0.63721	5.54260
1	2	1.82568	1.12548
1	3	-0.05726	5.36836
1	4	2.06977	3.36027
1	5	2.07190	1.43860
2	1	-2.24616	2.96021
2	2	-3.15762	3.54520
2	3	1.76342	9.76460
2	4	-1.09447	5.31139
2	5	3.80144	5.30008
		N = 15	N = 15

and is presented in Appendix J. The between groups factor was hemisphere trained (right trained group, left trained group) and the within group factors were sessions and nonfeedback trials (baseline and 4 nonfeedback rest trials). The Geisser-Greenhouse procedure was employed to test the within group effects. The results indicated a significant main effect of hemisphere trained, $F(1, 28) = 5.23, p < .05$; during nonfeedback trials hemisphere trained affected H-laterality scores. There were no other significant results.

Contingency Manipulation: Hemispheric Differences

Figure 7 illustrates the alpha time scores for the left contingent and noncontingent hemispheres and right contingent and noncontingent hemispheres during feedback trials. The alpha time scores for all hemispheres appear to increase over trials. Further, the slopes of the lines seem linear. Moreover, the alpha time scores of the right hemispheres appear to be fairly similar to each other, while the alpha time scores of the left hemispheres appear somewhat dissimilar. Figures 8 and 9 illustrate the same data collapsed over trials. From Figure 8 it appears that the block means of the left contingent hemisphere are higher than those of the left noncontingent hemisphere, while Figure 9 suggests that the block means of the contingent and noncontingent right hemispheres are similar. It also seems, from both figures, that the slopes of the block means are linear.

To determine whether the contingency manipulation differentiated contingent from noncontingent same-sided hemispheres during feedback trials, two between groups repeated measures ANOVAs were computed and

Figure Caption

Figure 7. Alpha time mean scores for the contingent and noncontingent left hemispheres and the contingent and noncontingent right hemispheres for sessions one and two. Each score represents the alpha activity during a 60 second feedback trial.

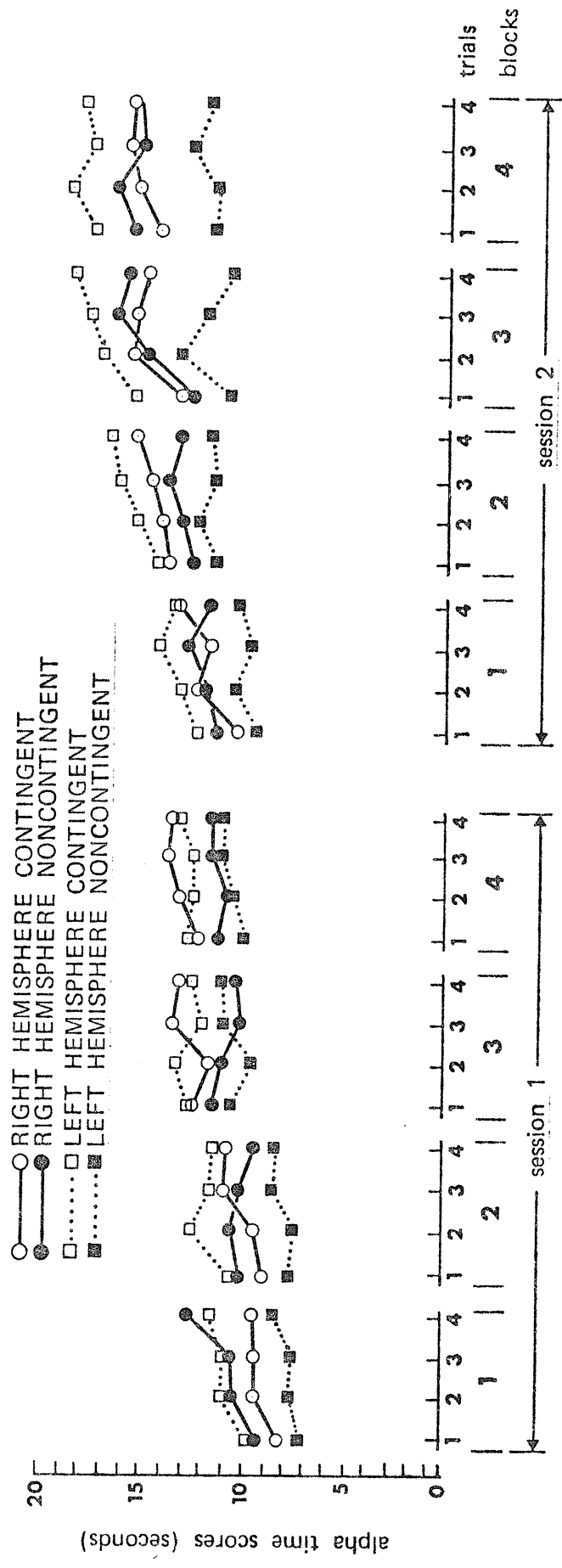


Figure Caption

Figure 8. Alpha time block means for the contingent and noncontingent left hemispheres for sessions one and two. Each mean is based on four feedback trial scores.

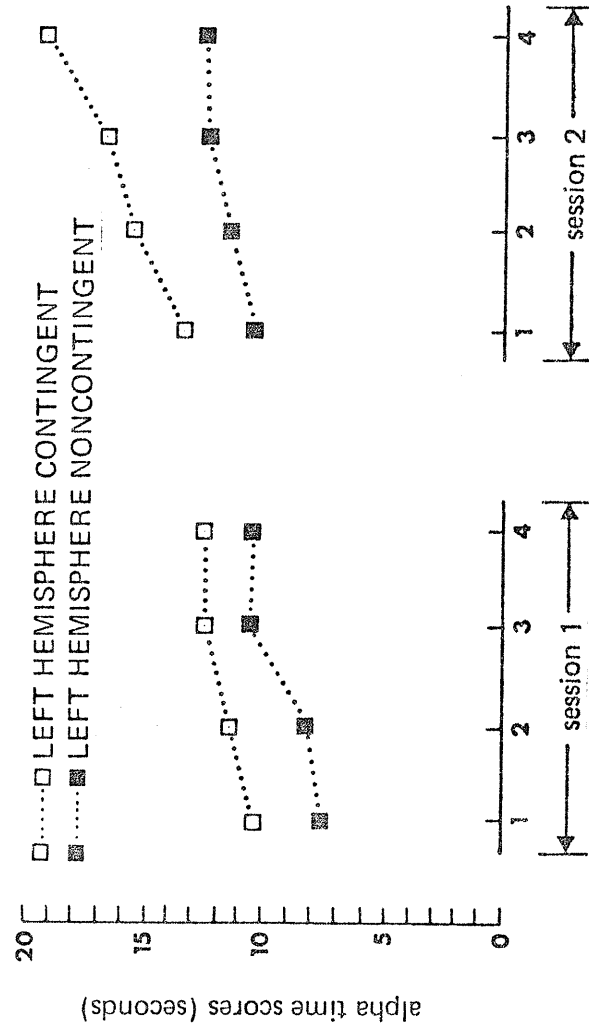
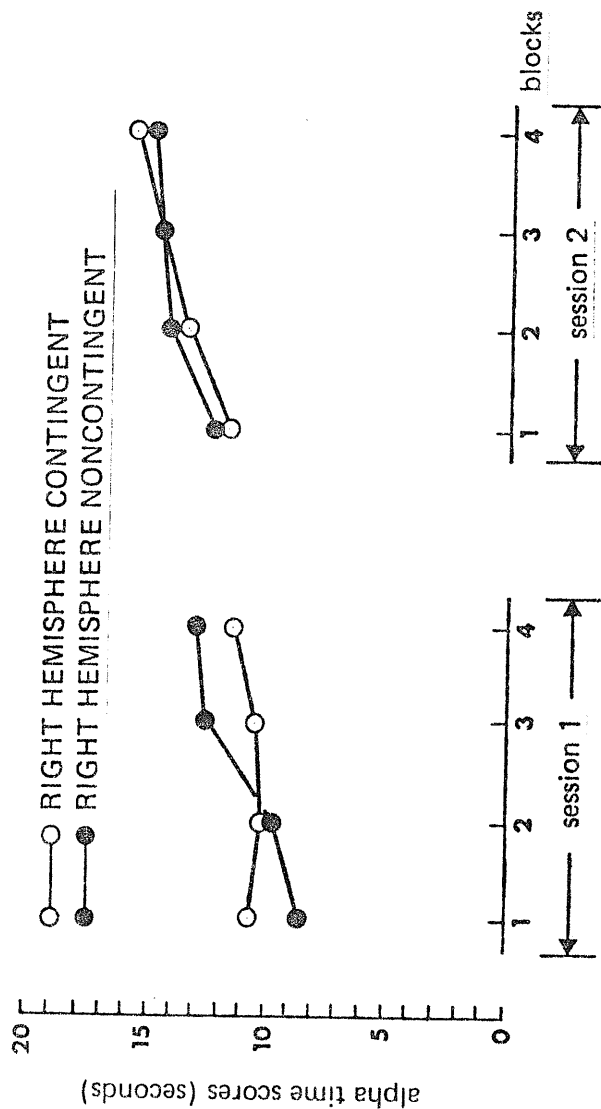


Figure Caption

Figure 9. Alpha time block means for the contingent and noncontingent right hemispheres for sessions one and two. Each mean is based on four feedback trial scores.



are presented in Appendices K and L. Each ANOVA examined the alpha time scores of a particular hemisphere when contingent and noncontingent. Thus, the between groups factor was contingency (either contingent left, noncontingent left hemisphere, or contingent right, noncontingent right hemisphere) and the within group factors were sessions, blocks, and feedback trials. Again, the Geisser-Greenhouse procedure was employed to test the within group effects.

The results of the ANOVAs indicated that the main effect of contingency was not significant for either the left or right hemispheres. Analysis did indicate that for the left hemispheres there were significant main effects for sessions, $F(1, 28) = 17.38$, $p < .01$, blocks, $F(1, 28) = 10.92$, $p < .01$, and trials, $F(1, 28) = 6.99$, $p < .05$, confirming the observation from Figure 7 that alpha time scores changed over training. Further, analysis of the right hemispheres indicated significant main effects for sessions, $F(1, 28) = 16.61$, $p < .001$, blocks, $F(1, 28) = 8.87$, $p < .01$, and trials, $F(1, 28) = 6.96$, $p < .05$, again confirming the observation from Figure 7. There were no other significant results. Finally, trend analysis confirmed the observations from Figures 8 and 9 that there was a significant linear component of the blocks main effect for the left hemispheres, $F(1, 28) = 18.50$, $p < .001$, and for the right hemispheres, $F(1, 28) = 16.58$, $p < .001$. Further, there was a significant linear component of the trials main effect for the left hemispheres, $F(1, 28) = 10.81$, $p < .01$, and for the right hemispheres, $F(1, 28) = 12.59$, $p < .01$.

Tables 3 and 4 present the means of the alpha time scores for

Table 3

Alpha time means for the contingent and noncontingent left hemispheres for sessions one and two for nonfeedback trials

Session	Trial	Means	
		Contingent Left	Noncontingent Left
1	1	9.29999	7.71266
1	2	7.96333	6.63266
1	3	8.44933	6.94799
1	4	9.05333	6.64599
1	5	9.95799	7.68666
2	1	10.79199	7.71666
2	2	11.41732	7.36466
2	3	11.81933	7.38332
2	4	10.97199	8.92799
2	5	10.55933	7.91666

N = 15

N = 15

Table 4

Alpha time means for the contingent and noncontingent right hemispheres for sessions one and two for nonfeedback trials

Session	Trial	Means	
		Contingent Right	Noncontingent Right
1	1	8.41266	9.27466
1	2	7.08599	8.26399
1	3	7.57799	8.51266
1	4	6.99266	8.51933
1	5	7.70666	9.30266
2	1	8.03199	11.01599
2	2	7.77266	11.57999
2	3	8.34866	11.43466
2	4	9.39733	10.61799
2	5	8.46333	10.15266
		N = 15	N = 15

the left and right hemispheres respectively during nonfeedback trials. As can be seen from the tables the means of the right hemispheres appear similar, as do the means of the left hemispheres. However, for both left hemispheres and right hemispheres the means for session two tend to be higher than those for session one. Note that the first mean of each session corresponds to the prefeedback baseline trial and that the remaining means correspond to nonfeedback rest trials.

In order to be certain that contingency did not differentiate same-sided hemispheres prior to feedback, independent sample t -tests on the alpha time prefeedback baseline means for the left hemispheres (contingent = 9.29999, noncontingent = 7.71266) and the right hemispheres (contingent = 8.41266, noncontingent = 9.27466) prior to session one were calculated. They were found to be nonsignificant: left hemispheres, $t(28) = 0.88$, $p = .389$, right hemispheres, $t(28) = 0.48$, $p = .389$. To determine whether contingency differentiated contingent from noncontingent same-sided hemispheres during nonfeedback trials, two between groups repeated measure ANOVAs were computed and are presented in Appendices M and N. Each examined the alpha time scores of a particular hemisphere when contingent and noncontingent. The between groups factor was contingency (either contingent left, noncontingent left hemispheres, or contingent right, noncontingent right hemispheres) and the within group factors were sessions and nonfeedback trials (baseline and 4 nonfeedback rest trials). Again, the Geisser-Greenhouse procedure was employed to test the within group effects. The results indicated that the main effect of contingency was not significant for

either left or right hemispheres. The main effect of sessions was significant for the left hemispheres, $F(1, 28) = 4.70$, $p < .05$, and the right hemispheres, $F(1, 28) = 7.01$, $p < .05$, confirming that the alpha time scores changed from session one to session two. There were no other significant results.

Comparison of Feedback to Nonfeedback Rest Trials

The mean alpha time scores for feedback trials and the mean alpha time scores for nonfeedback rest trials for each session under each of the contingency and hemisphere conditions (contingent left hemisphere, noncontingent left hemisphere, contingent right hemisphere, noncontingent right hemisphere) are presented in Table 5. To determine whether the alpha time scores of feedback trials would exceed those of nonfeedback rest trials, correlated sample t -tests were computed. The results indicated that the mean alpha time scores for feedback trials were significantly greater than the mean alpha time scores for nonfeedback rest trials during both sessions for all conditions (see Table 5).

Laterality Dominance Subtest

To determine whether the right and left trained groups differed on the lateral dominance score, an independent sample t -test for differences between groups was computed. There were no significant group differences, $t(28) = 1.57$, $p > .05$, as the mean for the right trained group was 20.00 and the mean for the left trained group was 19.50. This was as expected since all subjects were right-handed and from totally right-handed families.

Table 5

Mean alpha time scores for feedback and nonfeedback rest trials for sessions one and two and correlated sample t -tests comparing the means for feedback and nonfeedback rest trials

Contingency Condition	Session	Means		t Value	p
		Feedback	Nonfeedback		
Left Hemisphere Contingent	1	11.82143	8.85595	$t(56) = 3.3147$	$p < .01$
	2	15.95378	11.21699	$t(56) = 5.29458$	$p < .01$
Left Hemisphere Noncontingent	1	9.38623	6.97833	$t(56) = 3.13602$	$p < .01$
	2	11.77771	7.89816	$t(56) = 5.02690$	$p < .01$
Right Hemisphere Contingent	1	11.46928	7.34091	$t(56) = 5.06611$	$p < .01$
	2	14.08095	8.49549	$t(56) = 6.95427$	$p < .01$
Right Hemisphere Noncontingent	1	10.82523	8.64966	$t(56) = 2.57690$	$p < .05$
	2	14.05395	10.94632	$t(56) = 3.66599$	$p < .01$

Cognitive Strategies Questionnaire

In order to determine whether the groups differed in the cognitive strategies reported, (e.g., visual, verbal, emotional, etc.), a Hotellings T^2 for differences among group means on all levels of the strategy variables was computed. The results of the analysis was not significant, $T^2 = 5.2340$, $p > .05$.

t-tests for differences between the right and left group were computed for each strategy and were not significant (see Table 6). In addition, each strategy was reported by a similar number of subjects in each group. The majority of subjects from both groups (11/15 left group; 11/15 right group) reported using visual strategies at least half the time. Slightly more of the left group than the right group (8/15 left group; 5/15 right group) reported using verbal strategies at least half the time. Similarly, slightly more of the left group than the right group (9/15 vs. 5/15) reported using emotional strategies at least half the time. For the remaining strategies, even these slight differences disappeared. These results were contrary to what had been expected.

Table 6

t-test for differences between groups on the mean response
 given to each cognitive strategy subscale within the
 Cognitive Strategies Questionnaire

Cognitive Strategy Subscale	Mean Response (1-7)		<u>t</u> (28) value	Probability
	Right Group (N = 15)	Left Group (N = 15)		
Verbal	3.533	2.933	0.85	0.403 (NS)
Numeric	1.733	1.866	0.28	0.779 (NS)
Visual	4.467	4.600	0.21	0.836 (NS)
Musical	2.333	2.533	0.34	0.737 (NS)
Emotion	4.066	3.200	1.25	0.223 (NS)
Think nothing	2.400	3.066	0.97	0.341 (NS)

NS = not significant

Discussion

The overall findings of this study indicated that the contingent hemispheres generated more alpha activity than their noncontingent mates, resulting in specific patterns of asymmetry for the right trained and left trained groups. For both groups, the patterns of asymmetry (a greater percentage of alpha in the contingent than in the noncontingent hemisphere) were similar during feedback trials, though not necessarily during nonfeedback trials. The effectiveness of the contingency manipulation did not extend to same-sided hemispheres as the amount of alpha activity generated by the contingent and noncontingent left hemispheres and the contingent and noncontingent right hemispheres was similar. Further, the subjective reports of cognitive strategies employed did not differ between groups.

Contingency Manipulation: Group Differences

The present study determined that feedback contingent on the alpha activity of a single hemisphere resulted in higher alpha activity levels in that hemisphere compared to its noncontingent mate. Thus, for the right trained group, the right hemisphere generated a greater percentage of the lateralized alpha, while for the left trained group, the left hemisphere generated a greater percentage of the lateralized alpha. Further, the effects of contingency interacted with blocks, as the slope of the alpha laterality score of each group was linear but, as can be seen from Figure 4, in opposite directions. These results are consistent with those reported by other investigators (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977), that control of alpha activity was significantly better in the contingent than

in the noncontingent hemisphere. Moreover, the results of this study extend the effectiveness of contingent feedback to include auditory feedback as well as the visual feedback employed by the above mentioned researchers. Further, the patterns of asymmetry reported in this study were similar to specific patterns of asymmetry described by investigators (Davidson et al, 1976; O'Malley & Conners, 1972; Peper, 1971; Schwartz et al, 1976) employing the pattern biofeedback method. Therefore, for both the feedback method employed in this study and the pattern biofeedback method, the hemisphere for which alpha activity was the contingent response generated a greater percentage of that activity than its mate.

Davidson et al, (1976) reported that subjects, especially males, were somewhat more successful generating patterns of alpha asymmetry when right hemisphere alpha activity was to be enhanced rather than when left hemisphere alpha activity was to be enhanced. The findings of the present study appeared to confirm this report; there were no instances, when the right hemisphere alpha was contingent, of the noncontingent left hemisphere generating a greater percentage of the lateralized alpha, but when left hemisphere alpha was contingent, there were instances when the noncontingent right hemisphere generated more of the lateralized alpha. However, examination of the alpha time scores, from which the laterality measure was calculated, indicated that the alpha time scores of the noncontingent right hemisphere were higher than those of the noncontingent left hemisphere. While the differences were not large initially, they persisted and appeared to increase slightly over the course of the experiment. Moreover, for the contingent hemispheres, the alpha time scores of the left hemisphere seemed, by the end of the experiment, to be higher

than those of the right hemisphere. Therefore, for the laterality measure to reflect the same degree of success by the left trained group as by the right trained group, the alpha time scores of the left contingent hemisphere had to have been considerably higher than those of the right contingent hemisphere. While the overall picture then, is one of confirmation for Davidson et al's findings, the implicit assumption by Davidson et al, that differential success in generating patterns of asymmetry was due to some increased difficulty enhancing contingent left hemisphere alpha, was not confirmed. Alternately, the findings of this study indicate that perhaps Davidson et al's (1976) subjects, especially the males, had greater difficulty generating a $R\alpha$ off $-L\alpha$ on pattern due to an inability to maintain an absence of alpha activity in the right hemisphere rather than difficulty maintaining alpha activity in the left hemisphere. Further, contrary to the findings (Eberlin & Mulholland, 1976; Peper, 1972) that subjects increase and control alpha activity in the right hemisphere more successfully than in the left, observations from the present study suggested that subjects demonstrated a tendency for greater control over the alpha activity of the left hemisphere.

Hemispheric Reactivity: Group Differences

The present study indicated that the right and left trained groups responded similarly to the feedback training during feedback trials. The H-laterality scores of both groups increased significantly over blocks, reconfirming the observations of the previous section that the trained hemispheres generated a greater percentage of the alpha laterality than the untrained hemispheres and that both trained hemispheres reacted similarly to feedback.

That both groups responded similarly to feedback training suggests that processing of the feedback task was carried out in a similar fashion by both groups. Examination of the alpha time scores from which the laterality measure was computed, however, suggested that this may not necessarily have been the case.

Comparison of the alpha time scores of the contingent hemispheres suggested that, while the score for the hemispheres were similar during session one, the left hemisphere scores seemed higher during session two. Dimond and Beaumont (1976) reported that when each hemisphere was given the same task (in their case a vigilance task) the right hemisphere responded at a constant lower level, while the left hemisphere responded with increasing proficiency. If the feedback task is viewed as a vigilance task where subjects must attend to the auditory tone signalling alpha activity and respond to it with a continued burst of alpha activity, then the findings by Dimond and Beaumont could explain the aforementioned effect. The left hemisphere would respond at an increasingly higher level, while the right hemisphere responses remained constant. If, however, one considers the alpha time scores in the light of Semmes (1968) suggestion that the hemispheres process information differently, the right hemisphere in a diffuse fashion and the left hemisphere in a focal fashion, then it may be that the slightly elevated alpha time scores of the left hemispheres were due to processing differences. However, the nature in which the processing differences may have contributed to the differences in alpha time scores are difficult to determine.

Comparison of the alpha time scores of the noncontingent hemispheres indicated that the alpha time scores of the left hemisphere tended to be lower than those of the right hemisphere. This observation suggested that

the left hemisphere generates a lower level of alpha activity than the right unless under the specific feedback task conditions. The results of the analysis of the H-laterality scores during nonfeedback trials tended to support this observation. Laterality scores differed significantly between groups. Examination of the alpha time scores indicated that for the right trained group the right contingent hemisphere seemed to generate higher alpha time scores on all trials, while in the left trained group, the left contingent hemisphere seemed to generate higher alpha time scores on only half the trials. Further, the right noncontingent hemisphere appeared to generate higher alpha time scores than the left noncontingent hemisphere. These observations, again, point to a somewhat lower level of alpha activity in the left hemisphere than in the right hemisphere when neither is directly engaged in the feedback task. Moreover, these observations suggested that asymmetries in alpha frequency exist during resting conditions, as was reported by several investigators for alpha amplitude, (Doyle et al, 1974; Morgan et al, 1971; Smyk & Darway, 1972). Though the present study found that initial tests of group differences computed on the baseline scores prior to the first feedback trial were not significant, it may be that there is a tendency for the left hemisphere to maintain a lower frequency of alpha activity than the right hemisphere. Such a tendency would be consistent with available evidence. Consider that the hemispheres are superior at different functions, the left in language and analytic activities and the right in spatial, imaginal, and music activities. Further, the evidence indicates that during cognitive tasks, there is greater activation in the task-engaged hemisphere relative to the nonengaged hemisphere (i.e. Davidson

et al, 1976; Galin & Ornstein, 1972). Moreover, Dimond and Beaumont (1976) have suggested that the predominant cognitive mode is analytic. Lower alpha time scores in the left than in the right hemisphere when neither are engaged in the feedback task may then be explained by suggesting that the left hemisphere is normally engaged in analytic activity. Such an explanation would be consistent with prevailing thought.

Contingency Manipulation: Hemispheric Differences

The evidence from this study indicated that the alpha activity of contingent and noncontingent same-sided hemispheres did not differ. This finding differed from those reported by other investigators (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) who stated that self-control and enhancement of alpha activity was significantly greater in the contingent as compared with the noncontingent hemisphere. The previous studies compared contingent hemispheres to their noncontingent mates. Previous findings from this study suggested that such comparisons did indeed indicate greater control in the contingent hemispheres. The present comparisons were made between groups. It appears, then, that the assessment of the effectiveness of the contingency manipulation depends upon the type of comparisons made. Comparisons between mated hemispheres (within groups) indicated that the contingency manipulation was effective, while comparisons on same-sided hemispheres (between groups) indicated that it was not effective. A caution is therefore indicated that experimental design be considered when generalizing from a given set of data.

This observation has implications for feedback studies in general. It suggests that selection of a comparison group affects the evaluation of

the feedback manipulation. This observation is consistent with a report by Brolund and Schallow (1976), that the significance of biofeedback training differed depending on the type of control group employed, such that significant differences occurred between an experimental and a yoked-control group, but not between an experimental and no feedback control group (for a fuller discussion see Appendix C). These observations suggest that care must be taken to determine the adequate comparison or control group.

The findings of this study further determined that alpha time scores of the right hemispheres during feedback and alpha time scores of the left hemispheres during feedback increased significantly, in a linear fashion. As the alpha activity of the contingent as well as the noncontingent hemispheres increased significantly, it is apparent that at some point the activity of the noncontingent hemispheres must have received relevant feedback. This might be expected, especially as the noncontingent hemisphere did experience the feedback of their contingent mates (though not the feedback of the same-sided contingent hemispheres). Further, the hemispheres are highly interconnected (e.g. Dimond, 1972) and the likelihood that symmetrical alpha activity occurred between contingent and noncontingent mated hemispheres cannot be ignored.

Cognitive Strategies

The evidence from this study indicated that reports of cognitive strategies did not differ between hemisphere trained groups. This evidence is contrary to that reported by Schwartz et al (1976) that subjects reported specific strategies for specific patterns of asymmetry. Investigators of task dependent asymmetry (Butler & Glass, 1974; Doyle et al, 1974;

Galen & Ornstein, 1972; Morgan et al, 1971; 1974; Schwartz et al, 1976) have all reported that language and analytic tasks are correlated with less alpha activity in the left than in the right hemisphere, while spatial, holistic, and musical tasks are correlated with less alpha in the right than in the left hemisphere. In the present study the patterns of asymmetry were in the correct direction; however, subjects reported similar cognitive strategies for both patterns.

The administration of the Cognitive Strategies Questionnaire in the present study differed from that by Schwartz et al (1976). Schwartz et al administered the questionnaire after each discrete block of feedback trials, whereas, in the present study, the questionnaire was administered only once, at the end of the second session. This procedure was employed in order to minimize any bias or clues subjects could get from the questionnaire. Specifically, it was felt that the administration of the questionnaire during data collection could affect subsequent data collection. Unfortunately, verbal reports from subjects indicated that they had forgotten what strategies they had used in the first session. Therefore, the strategy chosen as that employed most frequently was the one which subjects used during the second session and thought that they had probably used in the first session. However, if subjects only reported those strategies used in the final session, the obtained patterns of asymmetry were such that differences in cognitive strategies between groups would have been expected. Therefore, it seems that there was no relationship evident between patterns of asymmetry and subjective reports.

A final comment must be made about the questionnaire itself. Verbal reports from subjects, during a debriefing period following the final session, indicated that the questionnaire may not have been sufficiently detailed. Subjects reported various classes of visual strategies. These were: visual motor-visualizing themselves engaged in some motor activity, visual picture-visualizing a single object, e.g., face, cube, tree, etc.; visual verbal-visualizing a progression of numbers, letters, or words; visual fixed - these subjects stared at the wall in front of them. It must be mentioned that all subjects had their eyes open and that the experimental chamber was dimly illuminated. Unfortunately, these verbal reports could not be classified by group.

It is obvious that subjects did employ cognitive strategies. It appears from the debriefing responses that the method of soliciting these strategies was not effective and that strategy categories need to be more detailed in order for a strategy questionnaire to be informative. However, the pattern of alpha asymmetry found in the present study were consistent with patterns reported by Schwartz et al (1976) and with patterns reported by investigators of task dependent asymmetry (e.g. Doyle et al, 1974). If patterning of neural activity underlies the emergence of cognitive and subjective experience as has been suggested (Schwartz et al, 1976), then one would expect that the presence of asymmetric EEG activity would be accompanied by specific cognitive experiences. As this was not the case in the present study, and given the limitations of the Cognitive Strategies Questionnaire, assessment of the validity of the aforementioned statement cannot be made.

General Consideration

The feedback paradigm employed in this study can be a valuable tool

for studying the EEG activity of the hemispheres. This paradigm enables the researcher to examine the activity of each hemisphere, while contingent and noncontingent, and to determine the effect of contingency on mated hemispheres. It enables determination of: the responses of individual hemispheric activity to a feedback signal; the contribution of each hemisphere to patterns of alpha asymmetry; and to some extent, the degree to which the alpha activity of homologous hemispheres are interrelated.

In terms of current theory, evidence from the present study was unable to illuminate a tangible relationship between hemispheric processing of information and cognitive activities. While specific patterns of asymmetry were generated, there were no specific cognitive strategies correlated with them. This raises the question of whether patterns of neural activity underly the emergence of cognitive and subjective experiences as was suggested by Schwartz et al (1976), or whether cognitive and subjective experience is somewhat causative of patterns of neural activity. The present study can offer support neither for nor against Schwartz et al and suggests that further research in this area needs to be undertaken.

Further, it appears that if hemispheric differences in processing of information do exist, that the feedback paradigm had limited effectiveness probing for them. Both trained hemispheres responded similarly to the feedback task, though the left hemisphere seemed to exhibit somewhat greater proficiency by the end of the experiment. It was mentioned that if one regards the feedback task as a vigilance task then the findings are consistent with reports by Dimond and Beaumont (1976) that right hemisphere performance is at a constant level, while left hemisphere performance increases in efficiency. This could indicate some difference

in hemispheric processing, but at this point it is impossible to say what the differences might be. Perhaps, if there had been differences in cognitive reports, some tentative conclusion could have been expressed.

The evidence of this study suggested that caution must be exercised in interpretation of feedback effects. Mulholland and associates (Eberlin & Mulholland, 1976; Mulholland, 1973; Mulholland & Eberlin, 1977) stated that control and enhancement of alpha activity is always greater in the hemisphere directly connected to the feedback path. This statement implied that this would be the case for mated pairings and for same-sided pairings. Mulholland and associates observed only mated pairings. The present study provided evidence consistent with the above statement for mated hemispheres. However, findings from same-sided pairings was not consistent with the abovementioned generalization. Further research investigating same-sided as well as mated hemispheres is indicated. It is suggested that shorter trial blocks to minimize any fatigue effects and a greater number of experimental sessions are necessary to fully examine the effects of the feedback task on paired hemispheres. It is further suggested that if reports of cognitive strategies are to be collected, a better instrument must be developed for soliciting these strategies.

In conclusion, the findings indicate that subjects can successfully self-generate specific patterns of alpha asymmetry and that these patterns are similar to those reported for pattern biofeedback training and for task dependent asymmetry. Unfortunately, the related cognitive concomitants have not been uncovered.

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APPENDICES

APPENDIX A

Handedness and Lateralization of Cognitive Functions

Historically, the hemisphere contralateral to the dominant hand was thought to be the dominant language hemisphere (Geschwind, 1976). Recent research has indicated that while this may be the case for the majority of right-handers (at least 2/3 of the population, Levy, 1976) it is not the case for all left-handers (e.g., Levy, 1976; Marshall, 1973; McGlone and Davidson, 1973; Warrington & Pratt, 1973). Evidence from neurological studies (reviewed by Levy, 1976) indicated that language function is lateralized in the right hemisphere of left-handed subjects in a minority (approximately 40%) of the cases. Warrington and Pratt (1973), employing unilateral ECT as a method of assessing language lateralization, reported that 25% of the non-neurological left-handed subjects evidenced right-hemisphere lateralization for language. It has been suggested that left-handers have a greater degree of bilateral representation of language function than right-handers (Hécaen & Lauguet, 1971; Levy, 1976; Suberana, 1969). Whether functions attributed to the right hemisphere in right-handers (i.e., spatial and other holistic functions), are lateralized to the right or left hemisphere in left-handers has not been determined. There has been some evidence to suggest that a left-hemisphere advantage may occur for some left-handed individuals in spatial and musical tasks (Gordon, 1974; McGlone & Davidson, 1973). Because of the confusion concerning lateralization of cognitive function in left-handed individuals, the majority of the research on lateralization of cognitive function has been conducted on right-handed subjects.

APPENDIX B

Cerebral Dominance and Resting Alpha Amplitude Asymmetries

Smyk and Darwaj (1972) investigated whether cerebral hemispheric dominance, as determined by seventeen tests of limbs, eye, and ear preference could be correlated with an asymmetry in the amplitude of the alpha rhythm during a relaxed state. From 166 subjects tested, the 34 with the highest indices of dominance or indifference between the hemispheres were chosen for EEG examination. These subjects were grouped into left dominant--13, right dominant--3, and indifferent--18. Analysis of the EEG records revealed an attenuation of the alpha amplitude over the left hemisphere in 15, attenuation over the right hemisphere in 6, and no difference between the hemispheres in 13 subjects. Correlation of the subjects' test results with the EEG results indicated that agreement between the two occurred only when 96-100% of the tests were positive (i.e., in the direction of left or right) otherwise, the tests were very poor predictors of EEG asymmetry. While significant differences in the alpha amplitude were reported for 21 subjects, in only two cases was concordance between tests and EEG results high enough for the asymmetry to be reliably attributed to cerebral dominance. Six cases were marginally concordant, 3 cases were discordant, and the remainder of the 21 cases were questionable. Therefore, although Smyk and Darwaj conclude that attenuation of the alpha rhythm amplitude in a relaxed state reflects domination of one hemisphere, it appears from their results that although there may be some asymmetry in alpha amplitude, this asymmetry cannot be said to reliably reflect cerebral dominance.

Butler and Glass (1974) have also addressed themselves to the

question of whether alpha amplitude asymmetry during a relaxed state was indicative of cerebral dominance. EEG recordings were taken from 41 right and left-handed subjects during an eyes-open and an eyes-closed condition and the alpha component was separated out by means of band pass filters. Analysis of the data revealed that there was very little asymmetry in the alpha rhythm amplitude whether subjects had their eyes open or closed. This alpha symmetry during rest conditions applied to both right and left-handed subjects. Butler and Glass concluded that there was no relationship between alpha asymmetry and cerebral dominance during rest.

There have been other investigators reporting either symmetry (Morgan, MacDonald, & Hilgard, 1974) or asymmetry (Doyle, Ornstein, & Galin, 1974; Morgan, McDonald, & MacDonald, 1971) in the amplitude of EEG alpha activity. Morgan et al. (1971) and Morgan et al. (1974) reported greater alpha amplitude over the right hemisphere during rest (or baseline) conditions in closed-eyed subjects. Morgan et al. (1974) found no alpha amplitude asymmetry during rest in an eyes-open condition. Doyle et al. (1974) reported that when subjects were instructed to attend to their breathing, which the authors equated with neutral resting condition, asymmetries such as those reported by Morgan et al. (1971) were present in the EEG records.

APPENDIX C

Methodological Considerations in Feedback Research

Many studies have illustrated that when human subjects are given exteroceptive feedback on the state of a physiological variable, they can learn to control that variable. The list of responses that can be controlled using a biofeedback technique include heart rate (e.g., Headrich, Feather, & Wells, 1971; Bergman & Johnson, 1972), blood pressure (e.g., Shapiro, Schwartz, & Turskey, 1972), human salivary response (e.g., Frezza & Holland, 1971), skin temperature (e.g., Roberts, Kewman, & MacDonald, 1973), single motor units (e.g., Leibrecht, Lloyd, & Pounder, 1973), and alpha rhythm (e.g., Dervan, 1968; Kamiya, 1968; Nowlis & Kamiya, 1970; Paskewitz & Orne, 1973; Valle, 1975).

Though many researchers (Brown, 1970; Kamiya, 1969; Nowlis & Kamiya, 1970; Peper, 1971; Valle, 1975), have reported that increases in occipital alpha activity occur with feedback training, there has been some question as to whether these increases were due to the actual feedback, or to habituation of the subject to the experimental situation with concomitant increases in alpha activity (Hart, 1968; Lynch & Paskewitz, 1971; Plotkin, 1976). There have been studies, however, demonstrating that increases in alpha activity were due to feedback and not habituation. Travis, Kondo, and Knott (1974a; 1974b) reported that subjects, given auditory feedback contingent on the presence of alpha rhythm activity, increased alpha activity significantly more than did subject receiving random auditory feedback, and subjects in a nonfeedback control group. These results have recently been questioned by Erolund and Schallow (1976). They suggested that interpretation of the data from the first study was complicated by

significant differences existant between the experimental and control groups at the beginning of training. Further, data from the second study were analyzed in terms of change scores from initial baseline, which would make it impossible to determine whether differences found between the groups were the reflection of initial baseline differences, or were the result of biofeedback training (cf. Brolund & Schallow, 1976).

Studies conducted by Beatty (1971; 1972), and Brolund and Schallow (1976) reported increases in the alpha activity levels of an experimental group given auditory feedback plus an extrinsic reinforcer. Beatty (1971; 1972) found that the probability of occurrence of alpha activity during one second sampling periods was significantly increased in subjects receiving auditory feedback contingent on enhancement of alpha activity relative to control subjects. Brolund and Schallow (1976) reported that subjects receiving auditory feedback plus extrinsic reinforcement performed significantly better than a feedback-alone group, a no-feedback control group, and a yoked-control group. They further reported that, while there was a significant difference between the feedback-alone group and the yoked-control group, there was not a significant difference between the feedback-alone group and the no-feedback control group. The authors suggested that in order to achieve overall significant increases in alpha activity subjects must receive adequate feedback plus extrinsic reinforcement. It would be interesting to know whether the differences in apparent success between the two experimental feedback groups (feedback plus extrinsic reward, feedback alone) were a result of the brevity of training (five 4-minute trials), or whether these effects would become more pronounced with longer periods of training. Further, it would be of interest to know

whether or not the extrinsic reinforcer served as an additional motivating factor. It has been suggested (Hardt & Kamiya, 1976) that for significant increases in alpha activity to occur, longer periods of training (i.e., two or more sessions) are necessary. Therefore, while feedback plus extrinsic reinforcement might have produced significant increases in alpha activity quickly, it may be that equivalent increases in alpha activity using auditory feedback without extrinsic reinforcement would develop over a longer period of time. Further, the possibility exists that the level of motivation of the subjects may play an important role in the successful generation of significant increases in alpha activity. An extrinsic reinforcer such as that employed by Brolund and Schallow (1976) might have increased the level of motivation of the subjects experiencing it above that of the other subjects and in this way, contributed to superior levels of performance. Kondo, Travis, and Knott (1975), in a study of the effects of motivation on alpha enhancement, reported that subjects receiving monetary reinforcement (\$5 to \$10) in addition to feedback, enhanced alpha significantly more than subjects who did not receive additional reinforcement, or who received only a small amount of reinforcement (\$2.50). These results suggest that performance might be linked to level of motivation. Therefore, while it appears that extrinsic reinforcement plus feedback is an effective combination over short term training at least, it is not clear whether that effectiveness is due to the extrinsic reinforcer itself, or to some increase in motivation.

The study by Brolund and Schallow also raised the issue of appropriate control groups. The results of their study indicated that

there was no significant difference between the feedback-alone-group and the control group, but that there was a significant difference between the feedback-alone and yoked control group. The author suggested that selection of an adequate control group could be an important factor in determining the effectiveness of the feedback treatment. The use of the "wrong" type of control group could lead to misleading conclusions. The results of this study imply that great care must be taken to determine the adequacy of control groups when interpreting the results of feedback research.

A further consideration involves the information value of the feedback signal. Feedback can be binary, in which case the feedback is either present or absent, or feedback can be proportional, in which case the feedback signal changes in intensity as the alpha amplitude or frequency increase or decrease. Hardt and Kamija (1976b) have suggested that proportional feedback is more effective than binary feedback. Review of the literature has suggested that this may be true in some cases (Travis et al, 1974a). Generally, reports of nonsignificant alpha enhancement have come from studies using binary feedback (Hord & Barber, 1971; Mulholland, 1972; Paskewitz & Orne, 1971; Peper & Mulholland, 1971; Walsh, 1974), while reports of significant enhancement of alpha activity have come from studies employing proportional feedback (Plotkin, Mazer, & Lowey, 1976; Plotkin & Cohen, 1976; Travis et al, 1976 a & b; Kondo et al, 1975). However, there have been reports of significant increases of alpha activity with binary feedback (Tutone, 1974), or with binary feedback plus additional information (Beatty, 1972; Brolund & Schallow, 1976; Hord, Lukin, Tracy, Jensma, & Johnson, 1976). At this

point it is not possible to determine whether proportional feedback is definitely and unquestionably more effective than binary feedback. However, the literature suggests that simple binary feedback may not be sufficient in and of itself to produce significant enhancement of alpha activity.

One further important issue to consider when studying alpha activity (either enhancement or suppression) is the effect of the oculomotor system. Alpha activity, especially occipital alpha activity, respond to eye opening and closing in that alpha activity is blocked during eye opening and returns when the eyes are closed (Mulholland, 1976; Plotkin, 1976). Plotkin (1976), and others, (e.g., Dewan, 1967; Mulholland, 1968; Peper, 1970, 1971) have shown that alpha enhancement and suppression can be controlled by oculomotor strategies (instructions to look or not to look). Plotkin, in a series of experiments conducted to determine if enhancement of alpha activity could occur independent of oculomotor strategies, reported that, subjects given proportional feedback regardless of the type of strategies (oculomotor, cognitive, none) they were instructed to employ, significantly increased their alpha activity above subjects not given feedback, but employing the identical strategies. Further, while subjects who received oculomotor instructions were more successful than others during a lights-on condition, there were no differences between subjects during a lights-off condition, even though subjects' eyes were open under all conditions. Experiments of this nature suggest that although increases in alpha activity can occur independent of oculomotor strategies, it is important to control both for eye movement and oculomotor strategies in order to be able to appropriately evaluate the data.

Related to the concern about the effects of the oculomotor system on alpha activity is the question of whether subjects are able to increase alpha activity above that level recorded with eyes closed in a dark room. Lynch and Paskewitz (1971) and Paskewitz and Orne (1973) have reported that occipital alpha levels cannot be significantly increased above the optimum baseline levels which are recorded with eyes open or closed when in a dark, quiet room. Tutone (1974), Plotkin (1976) and Travis et al (1974b) have reported small, though significant increases in alpha above these levels, Plotkin with eyes open, and Tutone and Travis et al, with eyes closed. Paskewitz and Orne (1973) and Plotkin (1976) found that addition of a dim ambient light enabled subjects to better control the alpha level and enabled production of significant increases above baseline.

The evident suggests that given adequate feedback, and under proper experimental conditions, subjects can learn to control their alpha activity.

APPENDIX D

LATERAL DOMINANCE EXAMINATION

NAME _____ DATE _____ EXAMINER _____

1. Show me your: right hand _____ left ear _____ right eye _____

2. Show me how you:	throw a ball	B	R	L
	hammer a nail			
	cut with a knife			
	turn a door knob			
	use scissors			
	use an eraser			
	write your name			

TOTAL _____

fold your hands _____ top thumb
fold your arms _____ tucked arm

3. Write full name: DH() _____secs. NDH() _____secs.
Write TELEVISION DH _____secs. NDH _____secs.

5. Show me how you: kick a football _____foot B _____
step on a bug _____foot R _____
cross your legs _____top leg L _____

6. ABC
(1) _____ (2) _____ (3) _____ (4) _____ (5) _____
(6) _____ (7) _____ (8) _____ (9) _____ (10) _____

7. Conclusions: Strongly L Mainly L Mixed Mainly R Strongly R
Hand _____
Foot _____
Eye _____

APPENDIX E

Instructions to All Subjects

Today and tomorrow you will be taking part in a biofeedback experiment. Biofeedback is a technique used to help people gain control over physiological activities not usually thought of as controllable, in this case brainwaves. You will have a chance, therefore, to learn to control your brainwave activity. To help us with our measurements and to provide you with feedback about your brainwaves, I will be attaching several surface electrodes to your head and arm. I will explain the purpose of each to you. The equipment you have seen will be used to monitor your brainwaves.

The session will last about 35 minutes and will consist of two parts: a 10 minute adaptation period, and about 25 minutes of learning to control a particular brainwave pattern. During the adaptation period your only task will be to sit quietly with your eyes open and to look straight ahead. You will hear a tone coming from the speaker in front of you. It will be on for a few minutes so that you can become used to the sound. The learning part of the experiment is broken into separate trials. During some of the trials you will be getting feedback or information about your brainwaves and during other trials you will not receive this information. When you hear one beep over the intercom, you will know that you will receive feedback in the subsequent trial. When you hear two beeps you will know that you will not receive feedback. It is important that you do not move around during this part of the experiment.

The tone you will hear from the speaker in front of you, during the

learning period, will provide you with feedback. The presence and volume of the tone indicates that the particular desired brainwave pattern is occurring. The tone will go on or off, and get louder and softer in response to that brainwave. When the tone goes off during the feedback trials, it means that the particular brainwave pattern has stopped occurring. When the tone is soft it means that you are producing only a small amount of the brainwave activity. When it is loud it means you are producing a great deal of the brainwave pattern. Your task will be to keep the tone on and as loud as possible. Do not worry if at first you cannot keep the tone on. This should be possible with practice. Are there any questions?

Because the records of brainwaves are very sensitive to movements, during the time I am monitoring your brainwaves I would like you to sit as quietly as possible, keep your eyes open, and look straight ahead. If you must adjust your position, please do so during the time when you know that you will not be receiving feedback. Remember, the only way to keep the tone on is with your brainwaves. To summarize, there are two parts to this experiment -- an adaptation part, and a learning part. During the adaptation part, your task is to sit quietly. The learning part is broken into trials, a feedback trial signalled by one beep, and a non-feedback trial signalled by two beeps. During the feedback trial your task is to keep the feedback tone on and as loud as possible. During the non-feedback trial, your task is to sit quietly. Do you have any questions?

The intercom connects this room with the next room. If you need to speak to me, or if you feel that you cannot continue in the project, simply call out.

APPENDIX F

Cognitive Strategies Questionnaire

To what extent would you say your strategy for turning on the tone involved the following kinds of thoughts?

Please circle the number which best represents your degree of involvement with each of the following six thought categories:

1 - not at all, 2 - slightly, 3 - less than half the time,
4 - half the time, 5 - slightly more than half the time,
6 - more than half the time, 7 - almost exclusively.

(a) verbal (e.g., talking to yourself)	1	2	3	4	5	6	7
(b) numerical (arithmetic, counting, etc.)	1	2	3	4	5	6	7
(c) visual (e.g., images)	1	2	3	4	5	6	7
(d) musical (e.g., tunes)	1	2	3	4	5	6	7
(e) emotional (e.g., feelings of anger, happiness, etc.)	1	2	3	4	5	6	7
(f) thinking nothing (e.g., blank mind)	1	2	3	4	5	6	7

APPENDIX G

Analysis of Variance on C-Laterality Scores: Contingency Effect During
Feedback Trials

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	4727.65625	1	4727.65625	3.37
C	54752.99219	1	54752.99219	39.00***
Error	39307.82031	28	1403.85059	
S	175.83984	1	175.83984	0.51
SC	169.60156	1	169.60156	0.49
Error	9726.74609	28	347.38379	
B	715.77344	3 (1)	238.59114	1.23
BC	5788.02344	3 (1)	1929.34106	9.97**
Error	16249.21094	84 (28)	193.44298	
SB	460.26563	3 (1)	153.42188	0.67
SBC	133.75391	3 (1)	44.58463	0.20
Error	19101.26172	84 (28)	227.39597	
T	92.71875	3 (1)	30.90625	0.26
TC	406.94531	3 (1)	135.64844	1.13
Error	10043.17188	122 (28)	119.56157	
ST	54.66406	3 (1)	18.22134	0.20
STC	575.31250	3 (1)	191.77083	2.10
Error	7663.39453	89 (28)	91.23088	
BT	847.99609	9 (1)	94.22179	1.05
BTC	783.85938	9 (1)	87.09547	0.97
Error	22641.66016	252 (28)	89.84785	
SBT	1401.63281	9 (1)	155.73697	1.86
SBTC	518.00000	9 (1)	57.55554	0.69
Error	21106.78906	252 (28)	83.75110	

(a) Numbers in parenthesis indicate the degrees of freedom employed for the conservative F-test.

C = Contingency

S = Sessions

B = Blocks

T = Trials

* $p < .05$

** $p < .01$

*** $p < .001$

APPENDIX H

Analysis of Variance on C-Laterality Scores: Contingency Effect During
Nonfeedback Trials

Source	Sum of Squares	Degree of Freedom (a)	Mean Square	F
Mean	11162.92578	1	1162.92578	5.23
C	1732.05078	1	1732.05070	7.80**
Error	66220.53516	28	222.16196	
S	198.10156	1	198.10156	1.21
SC	11.05469	1	11.05469	0.07
Error	4593.65625	28	164.05914	
T	359.33203	4 (1)	89.83301	0.61
TC	436.96484	4 (1)	109.24121	0.74
Error	16467.26172	112 (28)	147.02911	
ST	151.00781	4 (1)	37.75195	0.36
STC	347.13672	4 (1)	86.78418	0.83
Error	11735.66016	112 (28)	104.78267	

(a)

Numbers in parentheses indicate the degrees of freedom employed for the conservative F-test.

C = Contingency

S = Sessions

T = Trials

*p < .05

**p < .01

APPENDIX I

Analysis of Variance on H-Laterality Scores: Hemispheric Reactivity

Effect During Feedback Trials

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	54753.00391	1	54753.00391	39.00
H	4727.66016	1	4724.66016	3.34
Error	39307.99609	28	1403.85693	
S	169.60156	1	169.60156	0.49
SH	175.83984	1	175.83984	0.51
Error	9726.75391	28	347.38403	
B	5788.03125	3 (1)	1929.34375	9.97**
BH	715.77344	3 (1)	238.59114	1.23
Error	16249.19922	84 (28)	193.44284	
SB	133.75391	3 (1)	44.58463	0.20
SBH	460.26563	3 (1)	153.42188	0.67
Error	19101.26172	84 (28)	227.39597	
T	406.94922	3 (1)	135.64973	1.13
TH	92.71875	3 (1)	30.90625	0.26
Error	10043.16797	84 (28)	119.56152	
ST	575.31250	3 (1)	191.77083	2.10
STH	54.66010	3 (1)	18.22005	0.20
Error	7663.390063	84 (28)	91.23083	
BT	783.86328	9 (1)	87.09592	0.97
BTH	848.00000	9 (1)	94.22221	1.05
Error	22641.65234	252 (28)	89.84782	
SBT	518.00391	9 (1)	57.55598	0.69
SBTH	1401.63281	9 (1)	155.73697	1.86
Error	21106.78906	252 (28)	83.75710	

(a) Numbers in parenthesis indicate the degrees of freedom employed for the conservative F-test.

H = Hemisphere Trained

S = Sessions

B = Blocks

T = Trials

*p < .05

**p < .01

APPENDIX J

Analysis of Variance on H-Laterality Scores: Hemispheric Activity

Effect During Nonfeedback Trials

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	1732.05078	1	1732.05078	7.80
H	1162.92188	1	1162.92188	5.23*
Error	6220.53516	28	222.16196	
S	11.05469	1	11.05469	0.07
SH	198.10156	1	198.10156	1.21
Error	4593.65234	28	164.05901	
T	436.96484	4 (1)	109.24121	0.74
TH	359.33203	4 (1)	89.83301	0.61
Error	16467.25391	112 (28)	147.02905	
ST	347.13672	4 (1)	86.78418	0.83
STH	151.00781	4 (1)	37.75195	0.36
Error	11735.66016	112 (28)	104.78267	

(a) Numbers in parenthesis indicate the degrees of freedom for the conservative F-test.

H = Hemisphere Trained

S = Sessions

T = Trials

*p < .05

APPENDIX K

Analysis of Variance on Alpha Time Scores: Contingency Effect During
Feedback Trials for Left Contingent and Left Noncontingent Hemisphere

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	143703.50000	1	143703.50000	88.38
C	2622.63281	1	2622.63281	1.61
Error	45526.03906	28	1625.92993	
S	2553.77734	1	2553.77734	17.38***
SC	181.87109	1	181.87109	1.24
Error	4115.26563	28	146.97377	
B	1346.59351	3 (1) ^t	448.86450	10.92**
BC	28.96191	3 (1)	9.65397	0.23
Error	3453.92993	84 (28)	41.11821	
SB	53.04004	3 (1)	17.68001	0.53
SBC	134.03931	3 (1)	44.67976	1.35
Error	2784.67432	84 (28)	33.15080	
T	185.43213	3 (1)	61.81070	6.99*
TC	20.16675	3 (1)	6.72225	0.76
Error	742.60864	84 (28)	8.84051	
ST	24.49585	3 (1)	8.16528	1.31
STC	38.38452	3 (1)	12.79484	2.06
Error	522.57446	84 (28)	6.22112	
BT	14.07690	9 (1)	1.56410	0.21
BTC	38.18823	9 (1)	4.24314	0.58
Error	1852.98755	252 (28)	7.35312	
SBT	49.70850	9 (1)	5.52317	0.73
SBTC	46.24292	9 (1)	5.13810	0.68
Error	1897.68384	252 (28)	7.53049	

(a) Numbers in parenthesis indicate the degrees of freedom employed for the conservative F-test.

C = Contingency

S = Sessions

B = Blocks

T = Trials

*p < .05

**p < .01

***p < .001

APPENDIX L

Analysis of Variance on Alpha Time Scores: Contingency Effect During
Feedback Trials for Right Contingent and Right Noncontingent Hemispheres

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	150730.12500	1	150730.12500	96.10
C	9.00391	1	9.00391	0.01
Error	43916.53906	28	1568.44775	
S	2248.72241	1	2248.72241	16.61***
SC	5.66406	1	5.66406	0.04
Error	3790.66821	28	135.38100	
B	1095.97876	3 (1) ^t	365.32617	8.87**
BC	139.59302	3 (1)	46.53101	1.13
Error	3459.29468	84 (28)	41.18207	
SB	93.29492	3 (1)	31.09830	0.93
SBC	171.78906	3 (1)	57.26302	1.72
Error	2799.67480	84 (28)	33.32945	
T	225.11182	3 (1)	75.03726	6.96*
TC	17.32739	3 (1)	5.77580	0.54
Error	905.70581	84 (28)	10.78221	
ST	38.44385	3 (1)	12.81462	1.37
STC	27.92651	3 (1)	9.30884	0.99
Error	786.93896	89 (28)	9.36832	
BT	48.81763	9 (1)	5.42418	0.61
BTC	30.77710	9 (1)	3.41968	0.39
Error	2224.09619	252 (28)	8.82578	
SBT	51.00879	9 (1)	5.66764	0.57
SBTC	126.25000	9 (1)	14.02778	1.40
Error	2516.06128	252 (28)	9.98437	

(a) Numbers in parenthesis indicate the degrees of freedom employed for
for the conservative F-test.

S = Sessions

B = Blocks

T = Trials

C = Contingency

*p < .05

**p < .01

***p < .001

APPENDIX M

Analysis of Variance on Alpha Time Scores: Contingency Effect During
Nonfeedback Trials for Left Contingent and Left Noncontingent Hemispheres

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	23052.43359	1	23052.43359	95.12
C	485.70703	1	485.70703	2.00
Error	6785.97656	28	242.35629	
S	160.29224	1	160.29224	4.71*
SC	39.44995	1	39.44995	1.16
Error	935.14648	28	34.04094	
T	16.28540	4 (1)	4.07135	0.43
TC	5.60270	4 (1)	1.40070	0.15
Error	1053.38770	112 (28)	9.40525	
ST	40.04956	4 (1)	10.01239	1.45
STC	32.02368	4 (1)	8.00592	1.16
Error	775.66846	112 (28)	6.92561	

(a) Numbers in parenthesis indicate the degrees of freedom employed for the conservative F-test.

C = Contingency

S = Sessions

T = Trials

*p < .05

APPENDIX N

Analysis of Variance on Alpha Time Scores: Contingency Effect During
Nonfeedback Trials for the Right Contingent and Right Noncontingent Hemispheres

Source	Sum of Squares	Degrees of Freedom (a)	Mean Square	F
Mean	23886.99219	1	23886.99219	102.29
C	267.46094	1	267.46094	1.15
Error	6538.67188	28	233.52399	
S	172.50464	1	172.50464	7.01**
SC	33.56665	1	33.56665	1.36
Error	688.81665	28	24.60059	
T	7.99414	4 (1)	1.99854	0.21
TC	10.59766	4 (1)	2.64941	0.28
Error	1076.06763	112 (28)	9.60775	
ST	31.38110	4 (1)	7.84528	1.06
STC	26.98291	4 (1)	6.74573	0.91
Error	829.12207	112 (28)	7.40287	

(a) Numbers in parenthesis indicate the degrees of freedom employed for the conservative F-test.

C = Contingency

S = Sessions

T = Trials

*p < .05

**p < .001