THE EFFECTS OF EEG BIOFEEDBACK ON THE

NEUROPSYCHOLOGICAL CORRELATES

OF COGNITIVE PERFORMANCE

By

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Bachelor of Science

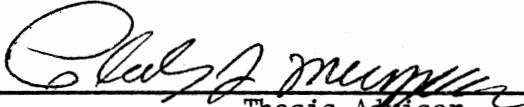Oklahoma State University

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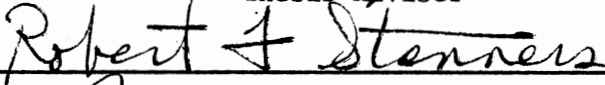for the Degree of
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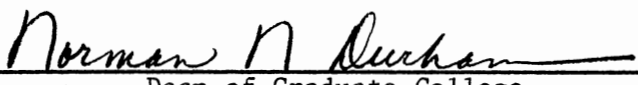
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ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

The fact that the cerebral hemispheres are specialized for perfor-
mance of different cognitive functions has been established by research
from several paradigms (see Appendix A). While many questions remain to
be answered concerning which hemisphere is dominant in processing cer-
tain complex tasks, the evidence shows that in most humans the left
hemisphere is specialized for verbal tasks and the right is specialized
for tasks involving spatial relationships.

Neurological evidence of cerebral lateralization existed more than
100 years ago and early in this century observations of brain damaged
patients lended more support to the theory (Taylor, 1958; Henschen,
1926). More recently, studies of commisurotomized patients suggested
that language comprehension and production occurs primarily in the left
hemisphere, while the right hemisphere is superior in the performance of
tasks requiring visual-spatial abilities (Sperry, 1967; Sperry, Vogel &
Bogen, 1970; Sperry, Gazzaniga, & Bogen, 1969). Because of the obvious
problems in generalizing results from research with brain damaged sub-
jects, non-obtrusive techniques have been developed for studying cere-
bral lateralization in normal subjects.

A number of well controlled studies have used EEG recording tech-
niques to demonstrate cerebral lateralization of function in normal
subjects. The most commonly used method is the comparison of specific

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wave forms or integrated power measures from different scalp locations while subjects perform verbal or visual-spatial tasks. These studies have found consistent differences in hemispheric EEG activity as a function of task type (Galin & Ornstein, 1972; Doyle, Ornstein & Galin, 1974; Dumas & Morgan, 1975; Morgain, MacDonald & MacDonald, 1971). It was established that verbal tasks produce proportionally higher arousal in the left hemisphere while the right hemisphere is proportionally more aroused by spatial tasks. One study (Doyle et al., 1974) observed a much greater task dependency when EEG activity was recorded for the alpha band alone.

Another paradigm that has successfully demonstrated cerebral lateralization in normal subjects utilizes tachistoscopic presentation of verbal and spatial material to the left or right visual field. Using reaction time or word recognition as the dependent measure it has been shown that subjects are more efficient in processing verbal or spatial material presented to sensory channels leading directly to the hemisphere dominant for processing each type of material (Klatsky, 1970; McKeever & Huling, 1970; Filbey & Gazzaniga, 1969; Moscovitch & Catlin, 1970). Reaction time studies have consistently shown that response latency is greater when information must be transmitted across the corpus callosum for processing.

The results of more recent research suggest that the assumptions derived from early visual hemifield experiments may be overly simplistic. It had been found that, in some simple spatial discrimination tasks, the left hemisphere was superior to the right. Attempts had been made to explain this discrepancy in terms of verbal codability of spatial elements in a simple task. However, Berlucchi et al. (1979) showed

that verbal codability was not sufficient to explain this phenomenon. Similar question were raised by Bradshaw, et al. (1979) who showed that, in some situations, lexical decisions were more accurate when performed by the right hemisphere. While not completely contradicting earlier findings, these results do suggest that the cerebral hemispheres may be differentially involved in different stages of information processing. It is possible that a combination of EEG recording techniques and tachistoscopic presentation of verbal and spatial material could help to answer some questions in this area.

EEG biofeedback is a very recent development, both as a therapeutic technique and as a research paradigm. Joseph Kamiya is recognized as a pioneer in this area, having gathered data on operant control of EEG alpha in the late 1950's (Gaarder, 1971). Since that time, a number of researchers have demonstrated the ability of human subjects to learn control of cerebral electrical activity through auditory and visual feedback (Kamiya, 1968; Brown, 1970; Nowlis & Kamiya, 1970; Peper, 1972; Hardt & Kamiya, 1976). Several of these studies have showed that different subjective mental states are associated with different levels of EEG activation. There is reasonable consensus that high alpha production is associated with relaxation and narrowing of perceptual awareness, while alpha blocking is linked to active vigilance, and moderate anxiety (Peper, 1970; Brown, 1970; Honorton et al., 1972).

Localized control of EEG activation was first reported by Peper in 1972. In only two sessions, he was able to train a subject to produce alpha at one scalp location while suppressing it at another location. He concluded tht localized training was feasible and, with the use of shaping techniques, that subjects could learn extremely fine control of

EEG patterns at selected locations. Nowlis and Wortz (1973) trained subjects to control their ratio of frontal to parietal alpha through auditory EEG biofeedback. Eberlin and Mulholland (1976) used a "yoked-cortex control" in assessing subjects' capabilities for localized control of alpha activity. This method uses as a control alpha activity in other cortical areas rather than the relaxation control groups used in other studies. Fox (1979) also used this method and was able to demonstrate selective hemispheric control of alpha.

With the associations of subjective states wth EEG activity and the localized control of EEG activity being well established, some researchers began looking at the possibility of enhancing cognitive performance through EEG biofeedback. Martindale and Greenough had hypothesized in 1973 that increases in level of arousal should lead to improvement in the performance of intellectual tasks because of the effect of drive level on cue utilization. Using relaxation, stress, and white noise conditions to produce different levels of activation they failed to find the hypothesized cognitive enhancement. However, their results did lead them to conclude that flexibility in changing levels of arousal may be a determinant of intelligence.

Of particular interest to the present study are a series of experiments conducted by Murphy and his associates since 1975. These studies have attempted to demonstrate enhancement of specific cognitive functions through EEG biofeedback training in both normal and learning disabled subjects. Murphy and Darwin (1975) gave unilateral left hemisphere alpha and beta training to learning disabled adolescents. They found that alpha training produced an increase in performance on an arithmetic task in addition to the expected changes in subjective mental states.

In another study of learning disabled subjects, Murphy, Darwin, and Murphy (1977) monitored alpha and beta band density during verbal and spatial tasks. They observed that a state of hypoarousal in both hemispheres in-task was typical of those subjects who showed evidence of cerebral dysfunction. This finding supported the earlier hypothesis (Martindale & Greenbough, 1973) that stated that the ability to change levels of arousal in the cerebral hemispheres is important to efficient processing of different types of material. In a further test of this hypothesis, Cunningham (1977) attempted to train this "plasticity" in learning disabled subjects through bilateral EEG biofeedback. Subjects who were trained to increase activation in the right hemisphere while decreasing activation in the left showed a significant improvement in arithmetic achievement. Subjects trained to decrease arousal in both hemispheres evidenced an improvement in reading comprehension. These results show an impact of EEG biofeedback training upon cognitive performance, but leave important questions unanswered about the role of activation in each hemisphere in performance of these tasks.

Using normal college-age subjects, Murphy, Lakey, and Maurek (1976) trained alpha enhancement in one hemisphere while training alpha suppression in the other. Comparing pre and post training verbal and spatial performance, they found that the group trained to increase left hemisphere alpha produced more variable verbal than spatial changes. Subjects trained to increase right hemisphere alpha produced the opposite pattern. In discussing possible explanations for these results, they speculated that, "Increased arousal training limits the plasticity of the processing; decreased arousal training enhances that plasticity, which is the first stage in enhanced competence in processing" (p. 3).

In a similar study, Murphy, Brown, and Adkins (1979) trained both bi-
lateral divergent and unilateral changes in hemispheric EEG. The only
significant improvement in cognitive performance occurred in one of the
unilateral training groups.

In each of the studies cited above, there is evidence suggesting
the possibility of enhancement of cognitive performance through EEG
biofeedback training. However, the mixture of results makes it dif-
ficult to formulate any definitive statements about the role of hemi-
spheric activation in processing competence. There are several method-
ological problems that could account for the inconsistency in these
findings. First, each of these studies used relatively complex verbal
and spatial tasks to evaluate efficiency of processing. Recent research
has raised questions about differential involvement of the cerebral
hemispheres in different stages of information processing. A cognitive
task requiring several seconds or more to process may involve a very
complex interaction between the hemispheres in formulating a response.
Second, each of these studies required subjects to make a written re-
sponse to the test stimuli. This response mode could introduce sig-
nificant intersubject differences in translation of mental decisions
into complex motor responses.

Another methodological problem involves the use of bilateral diver-
gent EEG training. Subject groups trained in this manner have con-
sistently shown large variation in their ability to produce the desired
changes. Until some more basic questions have been answered, this
training mode only serves to confuse the interpretation of both cog-
nitive performance and in-task EEG measures. The present study sought
to eliminate these possible sources of unexplained variability. The use

of simpler cognitive tasks with a very short processing time combined with a simple, reflexive response mode were used to gain a clearer picture of the effects of EEG training upon performance. Elimination of bilateral training groups made interpretation of data more managable.

CHAPTER II

METHOD

Subjects

The subjects were 30 college students chosen from undergraduate psychology classes at Oklahoma State University. These students received extra credit points in their psychology course for participating. Equal numbers of male and female subjects were used and this balance was maintained within the experimental and control groups. Only righthanded subjects were used. Screening for this was done by observing potential subjects' hand preference in using several simple tools (hammer, screwdriver, light switch) and through self report. Only those who showed a clear preference for use of the right hand considered themselves to be right-handed participated in the experiment.

Apparatus

EEG biofeedback was given to experimental group subjects via Autogen 120 encephalographic analyzer units manufactured by Autogenic Systems, Inc. During training sessions, one unit was used to deliver feedback information and to monitor brainwave activity in the hemisphere being trained. An identical unit was used to monitor activity in the hemisphere not undergoing training. It should be noted at this point, that the electroencephalogram is not a pure sinusoidal waveform. It is a complex AC waveform which is composed of a number of ocillatory cycles

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of different frequencies and amplitudes, superimposed over one another. The frequency component exhibiting highest amplitude at any given time is called the dominant frequency, while components having lower amplitudes are called non-dominant or sub-dominant frequencies. All EEG feedback and recordings for data analysis utilized the average dominant frequency recorded during the appropriate time period.

For ease of recording, each electroencephalograph unit was connected to an Autogen 5100 model digital integrator/wave form analyzer. These are data aquisition and scoring instruments which provide cumulative averages of EEG data and a percent time analysis for the selected EEG frequency band. During testing sessions, hemispheric EEG was recorded via the same system.

Control group subjects recieved skin resistance information from an Autogen 3400 feedback demograph. During all training and testing sessions their hemispheric EEG activity was monitored and recorded using the system described above. All feedback units used were battery powered and, therefore, presented no safety hazard to subjects or experimenters.

Test stimuli were presented to subjects using a Scientific Prototype brand three-channel tachistoscope. At the onset of the stimulus display, an electrical impulse from the tachistoscope control unit activated a Layfayette mode 6602A voice response time control that was adapted to respond to this signal. This unit started a Layfayette model 54417 millisecond counter. Subjects indicated their responses to the test stimuli using a three way toggle switch. By operating this switch, subjects simultaneously stopped the millisecond timer and notified the experimenter of their answer via a battery powered light system. A

permanent record of individual reaction times was provided by a printer attached to the timer unit.

Procedure

There were two EEG biofeedback training conditions: (1) training the left hemisphere to decrease the average dominant frequency (designated LD), and (2) training the right hemisphere to decrease the average dominant frequency (designated RD). Each EEG biofeedback subject received a total of four 20-minute training sessions in a period of five days. The control group was trained to increase skin resistance during four training sessions of the same length. The rationale for the use of GSR biofeedback as a control arises from several studies that show an association between somatic tension reduction and increased skin resistance (Davidson & Schwartz, 1976; Suter, 1977; Suter, 1979). These researchers have found that decreased autonomic arousal can be trained independently (at least in the short run) of the cognitive relaxation observed with EEG alpha training.

At the beginning of the first session, baseline data on EEG average dominant frequency and average amplitude were recorded for all subjects. During this five-minute period, subjects were asked to sit straight in the chair with feet on the floor, arms and legs uncrossed, and eyes opened. Left and right hemisphere occipital temporal EEG was monitored through four electrodes attached to the subject at positions Ol, O2, T3, and T4 with two reference electrodes on the forehead at positions Fpl and Fp2. During this same baseline period, control subjects' levels of micrmho skin resistance were recorded from two active electrodes placed on the thumb and little finger and a reference electrode on the middle finger of the left hand.

Immediately after the baseline period, the stimulus presentation and response units were placed in front of the subjects. The experimenter described the nature of the different stimulus materials and demonstrated how to respond "yes" or "no" with the toggle switch (see Figure 1 for examples). Verbal tasks involved viewing pronoun-verb combinations and determining whether or not the combination was syntactically correct.

Spatial stimuli consisted of two simple line drawings, one of which was rotated 45 degrees to the left. The task was to determine whether or not the two drawings were the same, outside of the difference in spatial orientation. Subjects were instructed to respond as quickly as possible, but not until they were certain that their answer was correct. All verbal and spatial items were designed to be easy enough for subjects to achieve a low error rate with little or no practice.

When subjects understood the nature of the tasks, they viewed and responded to 20 practice stimuli, grouped into four alternating blocks of five verbal or five spatial items. If a less than perfect performance was achieved on the last ten items, these were repeated. If, for some reason, a subject missed items on this second practice trial, he or she was dropped from the study. Following the practice period, subjects viewed and responded to a total of 40 test stimuli grouped into eight alternating blocks of five verbal or five spatial items. The time sequence of presentation for each item consisted of: (1) a three second fixation upon a central point, (2) a 110 millisecond stimulus presentation to the left or right visual hemifield, (3) an 8.9 second response and a rest period. Each item sequence occupied 12 seconds of the one-minute total time for each block. Items were presented alternately to

Stimulus Materials

Verbal	Correct Response	Spatial	Correct Response
He do	no		yes
They do	yes		no
She does	yes		no
I done	no		no
We does	no		yes
I do	yes		no
He go	no		yes
He goes	yes		yes
They go	yes		no
We goes	no		yes

Response Modes

Subject

3-way toggle switch

Subject   "yes" response

Subject   "no" response
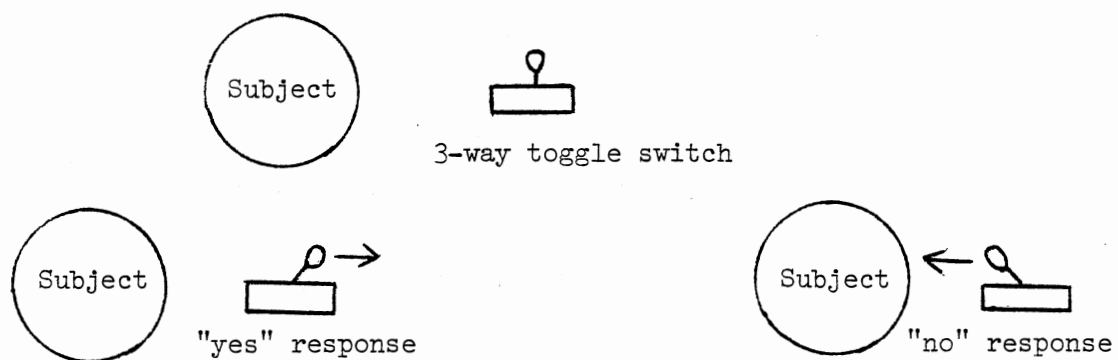
Figure 1. Examples of Stimulus Materials and Response Modes

the left or right visual hemifield so that one-half of the verbal and spatial items were presented to each hemisphere.

During each one-minute block of verbal or spatial itmes, the printer recorded the separate reaction times for each response. The average dominant EEG frequency and the average EEG amplitude were computed for each oneminute period and these were recorded by the experimenter. After each block, there was a 15 second break during which the subjects were able to raise their eyes from the optical unit. This also allowed the experimenter to clear the values registered on the equipment and prepare it to compute the next set.

Immediately following the pretest, subjects began their first 20-minute biofeedback training session. Both experimental and control groups recieved audio feedback via headphones. The EEG subjects were first familiarized with the feedback sound which is a type of white noise. They were also shown the sound that muscle artifact produces (a crackling sound) and the noise produced by a displaced electrode (a buzzing sound). They were instructed to keep all sounds off as much as possible by any internal strategy that worked. Subjects were also told that, if at any time during the experiment they were able to keep the sound off easily, the experimenter would move the criterion threshold to make it more difficult. When this happened, they would hear a burst of feedback noise following a quiet period, which meant they were doing exceptionally well. At this point experimenters reemphasized the instruction that subjects were to keep their eyes opened at all times and subjects were checked periodically to insure compliance. This was done to control for variability in EEG which might be introduced by varying light intensities as found by Paskewitz and Orne (1973). Control group

subjects received the same instructions, except the portion concerning muscle artifact and displaced electrodes which are not problems with the dermograph.

After these initial instructions, all subjects were asked to assume the position maintained during the baseline period. For the EEG subjects, thresholds were set at 2 Hertz (the lowest graduation on the Autogen 120a) and at the average dominant frequency recorded during the relaxed baseline period. The percent time interval was set at 100 seconds and the subject instructed to begin trying to control the feedback. If, at any time during the session, the subject was able to keep the percent time meter below ten percent for at least 30 seconds, the upper threshold was lowered by 1/2 Hz. At the beginning of each subsequent training session, the upper threshold was set at 1/2 Hz. above the lowest level achieved during the previous session.

For dermograph subjects, threshold was set at two micromhos below the highest level maintained for at least 30 seconds during the baseline period. If, at any time during the session the subject was able to keep the meter below threshold for at least 30 seconds, the experimenter decreased the threshold by one micromho. At the beginning of each subsequent session, the threshold was set at one micromho below the lowest level achieved during the previous session. The second, third, and fourth sessions for all groups were held on separate days and involved only a recap of the instructions and 20 minutes of feedback training.

On the fifth day of the experiment, subjects did not receive feedback. In this session all electrodes were connected and the experimenter recorded baseline data under the same conditions as during the

initial baseline period. After this, all subjects performed the same practice routine used in the first session, with the exception of the repeat trial used for missed items. Subjects then viewed and responded to 40 novel test stimuli and posttest reaction times and the EEG data were recorded in the same manner as that of the pretest.

Design

Independent Variables

The between groups variable used in analysis of cognitive changes in this study was Treatment Condition. Ten subjects were assigned to each of two EEG conditions (LD and RD) and ten were assigned to the dermograph condition (control). The within group factors are stimulus type and hemisphere of presentation. The stimulus type factor consisted of two qualitative levels: verbal and spatial. The hemisphere of presentation factor had two levels: left hemisphere and right hemisphere.

In the analysis of changes in in-task hemispheric EEG, the same within and between group variables used with the cognitive measure were used. For measures of changes in baseline EEG, treatment condition was the between groups variable. The within group factor, hemisphere, had two levels, right and left hemisphere. In this baseline EEG analysis, stimulus type was not a variable.

Dependent Measures

Measures of changes in cognitive processing efficiency were obtained by subtracting posttest reaction time from pretest reaction time within each of the levels of the independent variables. Separate sets

of difference scores were computed for baseline EEG average dominant frequency and average amplitude for the left and right hemispheres. These were obtained for each cell formed by the combinations of independent variables by subtracting fifth session baseline values from first session baseline values. In-task EEG difference scores were computed in the same manner for all of the combinations used in the analysis of processing efficiency.

Hypotheses

1.   EEG biofeedback groups were expected to show decreases in average frequency and increases in average amplitude in the trained hemisphere from the first session baseline to the fifth session baseline.

2.   The control group was not expected to show any systematic change in EEG amplitude or frequency from the first session baseline to the fifth session baseline.

3.   All groups were expected to have faster reaction times and lower error rates on verbal and spatial material presented to the dominant hemisphere than to material presented to the nondominant hemisphere.

4.   Experimental groups were expected to differ from the control group in reaction time and error rate differences from pretest to posttest on both verbal and spatial test stimuli.

5.   LD and RD groups were expected to differ from each other in reaction time and error rate differences from pretest to posttest on verbal and spatial material.

6.   In-task EEG measures for all groups were expected to differ as a function of task type and hemisphere of presentation combinations on pretest and postest.

7.   Differences from pretest to posttest on in-task EEG measures were expected to differ from experimental and control groups.

8.   Differences from pretest to posttest on in-task EEG measures were expected to differ for LD and RD groups.

CHAPTER III

RESULTS

In order to clearly describe the large volume of data yielded by the experimental procedure, the results will be presented in four sections. The first section will examine the changes in baseline EEG measures from the pretest session to the posttest session among the two experimental groups (left and right hemisphere EEG training) and the control group (GSR training). The second section investigates the changes in cognitive performance among the groups as measured by reaction time and error rate within each combination of cognitive task and hemisphere of presentation. The third section examines the differences in in-task EEG measures as a function of task and hemisphere combinations. Also, the changes in these measures from pretest to posttest will be examined. The fourth section will contain descriptions of several supplementary analyses performed on physiological and cognitive measures recorded during training and testing of subjects.

Baseline EEG Measures

In order to test Hypothesis 1, separate dependent samples t tests (Table I, Appendix B) were performed seeking differences between pretest and posttest baseline EEG measures in the left hemisphere for the left-down training group (LD) and in the right hemisphere for the right-down training group (RD). The LD group showed a significant mean decrease in

left hemisphere frequency of 2.909 Hz from pretest to posttest baseline $t(9)=2.73$, $p < .025$, but showed no change in left hemisphere amplitude. The RD group showed no significant differences in either measure for the right hemisphere. These results initially appeared to constitute a partial confirmation of the hypothesis. However, further examination of the left frequency data for pretest baselines indicated possible differences among the treatment groups on this measure. A one-way analysis of variance (Table II, Appendix B) performed on the group means showed the presence of one or more significant differences, $F(3,27)=3.36$, $p < .05$, so Duncan's Multiple Range Test and Tukey's HSD procedures were performed on all pairwise comparisons. Duncan's test showed all means to be significantly different, $p < .05$. The more conservative Tukey's procedure showed significant differences between the LD and GSR groups and between the LD and RD groups (both at $p < .05$), but showed no difference between the GSR and RD groups.

In either case, this pretreatment difference in the LD group's left frequency precludes interpretation of the pretest to posttest decrease as a treatment effect based upon the dependent measures t test. To further test this assumption, an analysis of covariance was performed on the posttest baselines for left frequency using the pretest baselines as the covariate. This analysis showed no significant differences among the group means, confirming the absence of treatment effects upon left hemisphere frequency.

Hypothesis 2 predicted that there would be no pretreatment to posttreatment changes in EEG measures for the GSR biofeedback (control) group. The dependent samples t test failed to reject this null hypothesis for left and right frequency and left amplitude measures. The

control group did, however, show a significant mean decrease in right hemisphere amplitude of .182 mv, $\underline{t}(9)=2.49$, $\underline{p}<.04$. Since decreased amplitude is generally associated with higher arousal in a specific hemisphere, it might be expected that this change would be accompanied by an increase in right hemisphere frequency, but this result was not found.

The dependent samples $\underline{t}$ on the GSR group's changes in skin conductance from pretest baseline to posttest baseline showed no significant change, indicating that any effects obtained in training sessions did not generalize to the final testing session. A Sex (2) x Session (4) x Trial (5) ANOVA was performed on control group measures of in-training skin conductance (Table XVIII, Appendix B) to determine whether or not feedback impacted GSR within or across training sessions. A significant main effect for trials (within sessions) was found, $F(16, 128)=3.79$, $p<.0001$. Examination of the trial means showed a linear decrement in skin conductance from the first trial through the fifth trial. This indicates that subjects experienced a relatively steady decrease in autonomic arousal within training sessions, either as a result of training or habituation to the laboratory environment (or both).

To test for possible sex differences in subjects' responses to treatments, four separate Group (3) x Sex (2) ANOVA's were performed on the pretest to posttest differences in measures of left and right hemisphere frequency and amplitude (Table III, Appendix B). For the left frequency differences, a significant main group effect, $\underline{F}(2,24)=5.05$, $\underline{p}<.02$, was found. This effect was disregarded for the reasons discussed above. A nonsignificant group by sex interaction was also found,

$\underline{F}(2,24)= 2.71$, $\underline{p}<.09$, for left frequency change. The ANOVA's for right

frequency and for left and right amplitude differences showed no signif-

icant main effects or interactions.

Reaction Time and Error Measures

Six mixed model ANOVA's were performed on reaction time and error

data from the experimental and control groups. Group (3) x Sex (2) x

Task Type (2) x Hemisphere of Presentation (2) ANOVA's were performed

separately on pretest and posttest reaction time and errors and on the

differences in these measures from pretest to posttest (Tables IV-IX,

Appendix B). In the analyses of error rate data there was a concern

that, due to the relatively simple nature of the cognitive tasks, there

would be a large proportion of cell totals equalling zero. If so, this

would result in an asymmetrical distribution of scores that was posi-

tively skewed, which would constitute a violation of the assumption of

normally distributed errors for the $\underline{F}$ ratio. However, examination of

the cell totals showed that percentages of zero error rates ranged from

ten to thirty-four percent for different task/presentation combinations

on pretest and posttest. It was concluded that this did not represent a

significant violation of the normality assumption.

For the sake of clarity and conciseness, in this and the following

chapter, the term "dominant hemisphere" will refer to the hemisphere

presumed to be specialized for processing a particular type of stimulus

item (left for verbal and right for spatial items). The term "nondom-

inant" will refer to the hemisphere not specialized for processing a

particular stimulus (right for verbal and left for spatial).

A significant main effect was found on pretest errors as a function of hemisphere of presentation, $F(1,24)=13.68$, $p<.0011$. The pretest error mean for items presented to the right hemisphere was 1.8 as opposed to a mean of .983 for items presented to the left hemisphere. A significant task by hemisphere interaction was also found for pretest errors, $F(1,24)=35.34$, $p<.0001$. The planned comparison of means for material presented to the dominant and nondominant hemispheres showed a significantly higher number of errors on items presented to the dominant hemisphere, $t(116)=3.811$, $p<.001$, which is contrary to the prediction made in Hypothesis 3 which states that error rates are expected to be lower for tasks presented to the dominant hemisphere for each task type. Further comparisons showed no significant differences for any pairwise comparisons of verbal/left, verbal/right, and spatial/left combinations. Comparison of the spatial/right combination to the means for the other three showed a significant difference, $t(116)=9.87$, $p<.001$, indicating that the divergence of this particular mean was responsible for the significant interaction (see Figure 2).

On measures of pretest reaction time a significant main effect, $F(1,24)=16.69$, $p<.0004$, was found for task type. The mean millisecond reaction time for spatial items (1161 ms) was faster than the mean for verbal items (1371 ms). There was also a significant sex by presentation interaction, $F(1,24)=5.9$, $p<.02$. The fastest mean reaction time was for females with right hemisphere presentation (1193 ms), followed by females/left (1240 ms), males/left (1275 ms), and males/right (1356 ms). Tukey's procedure for comparison of these means yielded a critical difference of 29.55 ms, which shows all of these means to differ significantly at $p<.05$. Across sexes, females were faster than males. Within
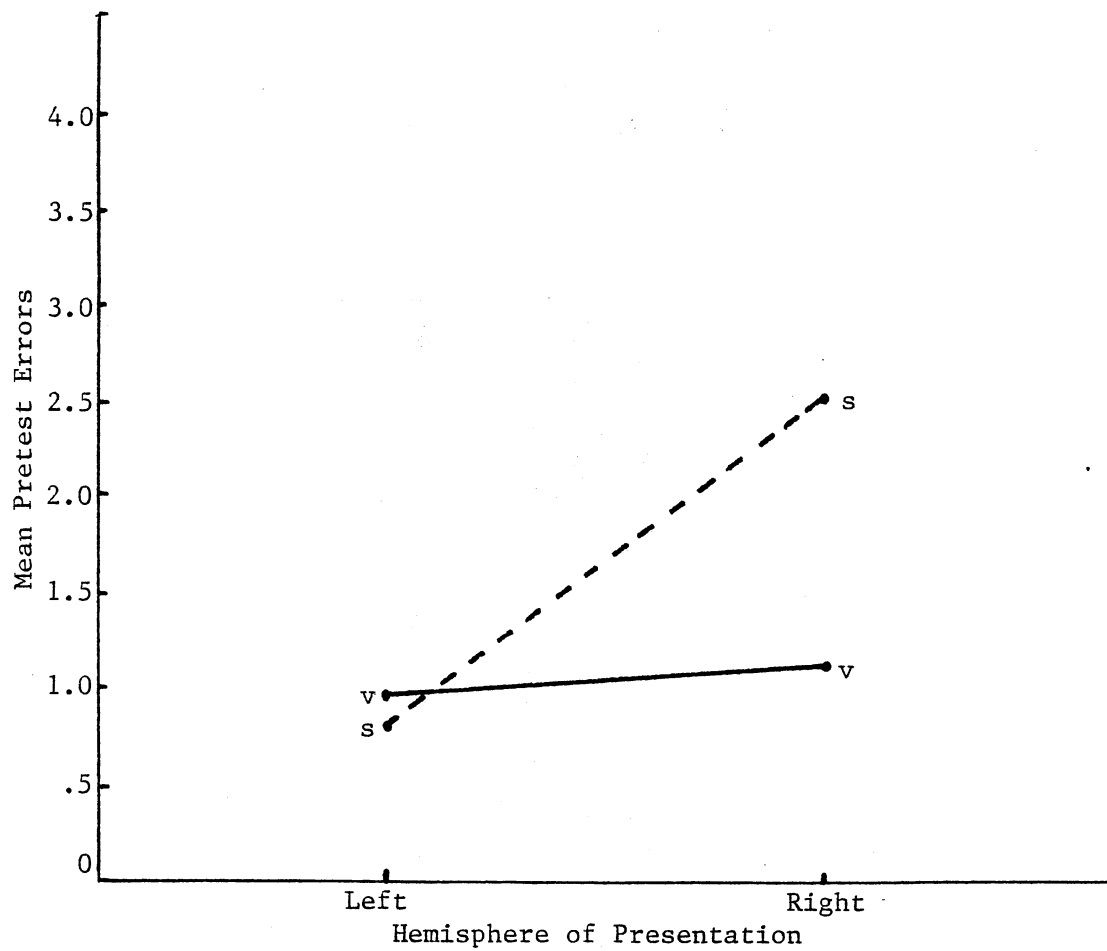
Figure 2. Task x Presentation Interaction on Pretest Errors for Verbal (v) and Spatial (s) items

sexes, females were faster with right presentation and males were faster with left presentation (see Figure 3).

On posttest errors there was a significant main effect for task type, $F(1,24)=20.17$, $p<.0001$, and also for presentation, $F(1,24)=30.9$, $p<.0001$. Mean errors were greater for spatial items (1.96) than for verbal items (.967) and greater for right hemisphere presentation (1.96) than for left (1.03). As with pretest errors there was a significant task by presentation interaction, $F(1,24)=45.56$, $p<.0001$ (see Figure 4). The first planned comparison tested for differences in error rates for tasks presented to the dominant hemispheres (verbal/left and spatial/ right) and nondominant hemisphere (verbal/right and spatial/left). This difference was found to be significant, $t(116)=6.55$, $p<.001$, with error rates being higher for presentation to the nondominant hemisphere. However, for verbal items presented to the dominant and nondominant hemispheres there was no significant difference. For spatial items presented to the left hemisphere the error rate was significantly greater than for spatial/right, $t(116)=8.84$, $p<.001$. An additional comparison tested mean errors for spatial/left against the pooled means for the other three combinations and found spatial/left to be significantly higher, $t(116)=46.53$, $p<.001$. As was the case in the pretest errors task by presentation interaction, the divergence of one mean appears to be responsible for this effect. However, on posttest, the spatial/left combination was divergent rather than the spatial/right (see Figure 4).

There was also a significant task by presentation interaction for posttest reaction times, $F(1,24)=21.85$, $p<.0001$ (see Figure 5). The contrast of the pooled means for tasks presented to the dominant and
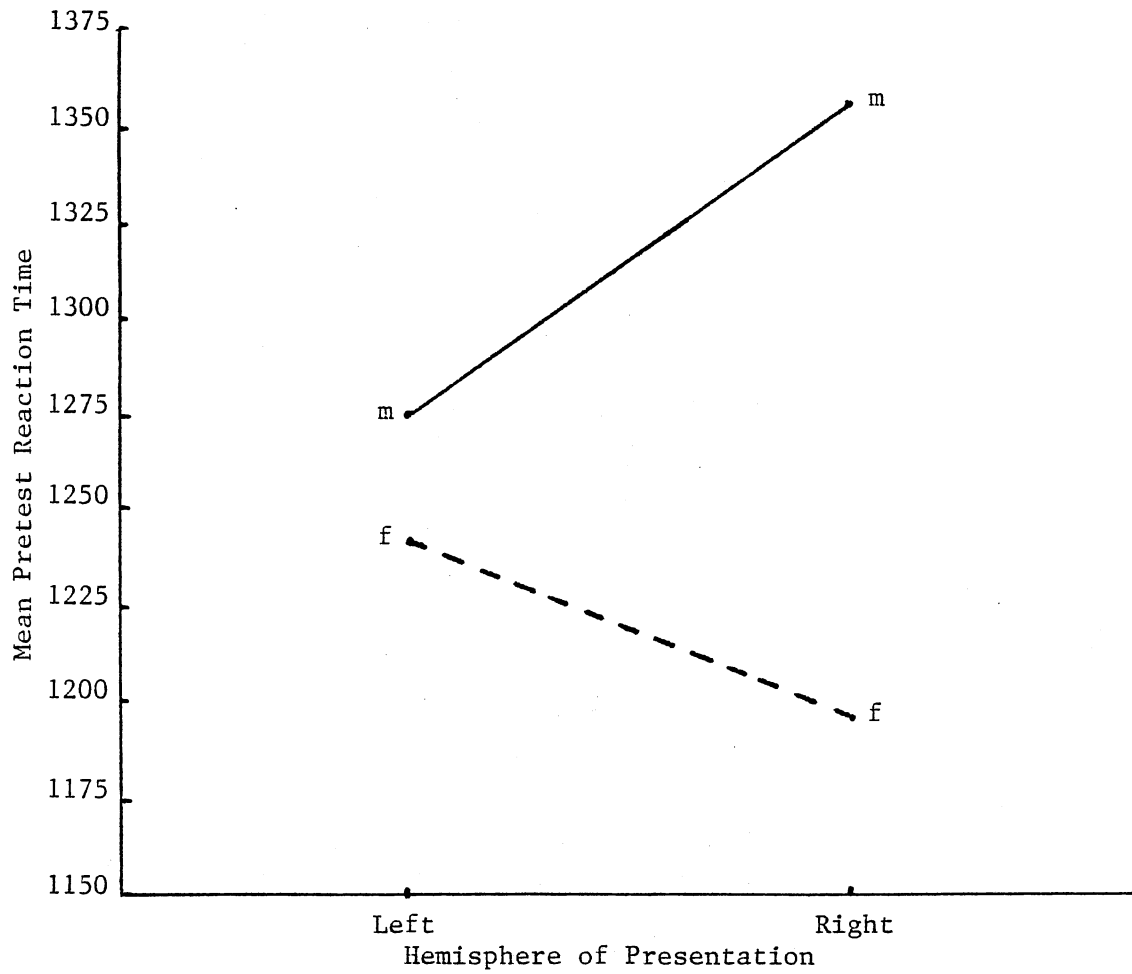
Figure 3. Sex x Presentation Interaction on Pretest Reaction
Time for Male (m) and Female (f) Subjects
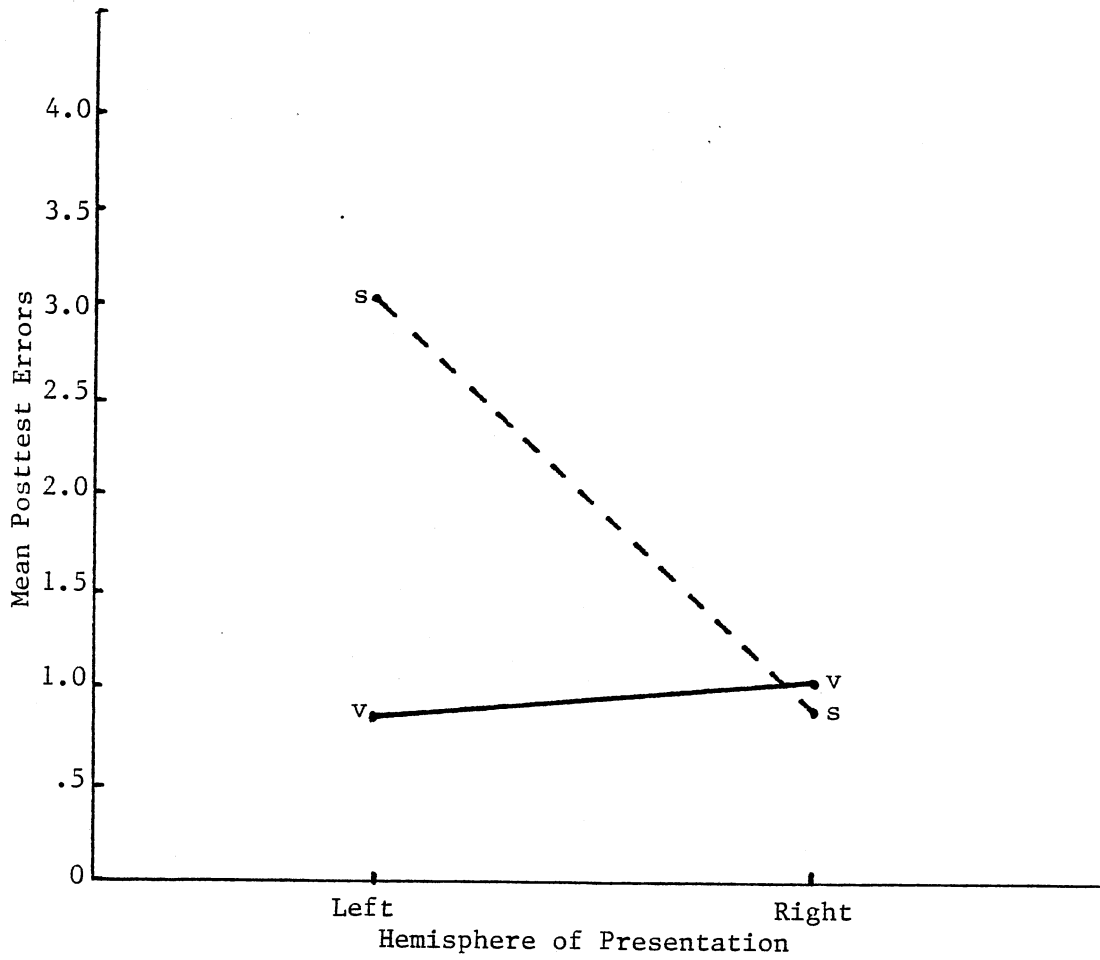
Figure 4. Task by Presentation Interaction on Posttest Errors
for Verbal (v) and Spatial (s) Items
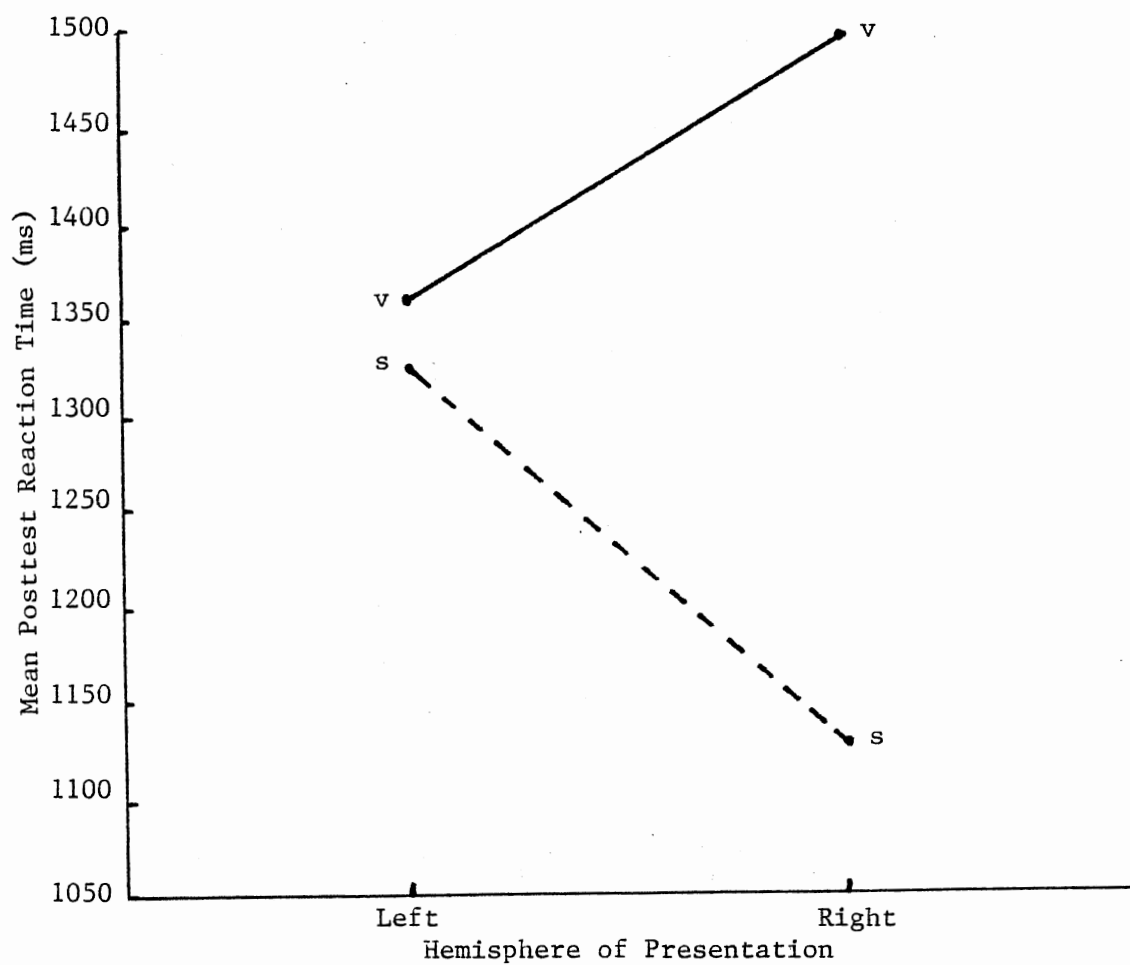
Figure 5. Task x Presentation Interaction on Posttest Reaction
Times for Verbal (v) and Spatial Items (s)

nondominant hemispheres showed that presentation to the dominant hemisphere produced significantly faster reaction times, t(116)=4.68, p<.001. Further comparisons showed that responses to verbal items were faster for left than for right presentation, t(116)=3.871, p<.001, and that responses to spatial items were faster for right than for left presentation, t(116)=.498 p<.001. These results confirm the prediction of Hypothesis 3 for posttest reaction times. This predicted interaction was not found on pretest reaction times, but this may have been due to the high level of within-groups variability on this measure.

To test the effects of treatments upon cognitive performance, ANOVA's were performed on the pretest to posttest differences in errors and reaction times. A nonsignificant, but suggestive, main effect for treatment groups was found on pretest to posttest reaction times differences, F(2,24)=2.96, p<.0711. Because Hypotheses 4 and 5 predicted treatment group effects upon this measure, planned comparisons were performed on the group means. The two most extreme mean changes were for the LD group (-145.5 ms) and the RD group (51.43 ms). Comparison of these two means yielded t(27)=1.817, whose probability level fell between .05 and .1. A significant group by sex interaction was found for error differences, F(2,24)=3.84, p<.04 (see Figure 6). In the GSR training group both male and female subjects made more errors on the posttest than on the pretest, with females showing a greater mean increase than males (.45 and .15 respectively). LD group males showed a mean decrease of .6 errors from pretest to posttest while females increased mean errors by .25. In the RD group males increased errors by a mean of .75 and females decreased mean errors by .55. Tukey's HSD procedure for these six means yielded a critical difference of 1.76.
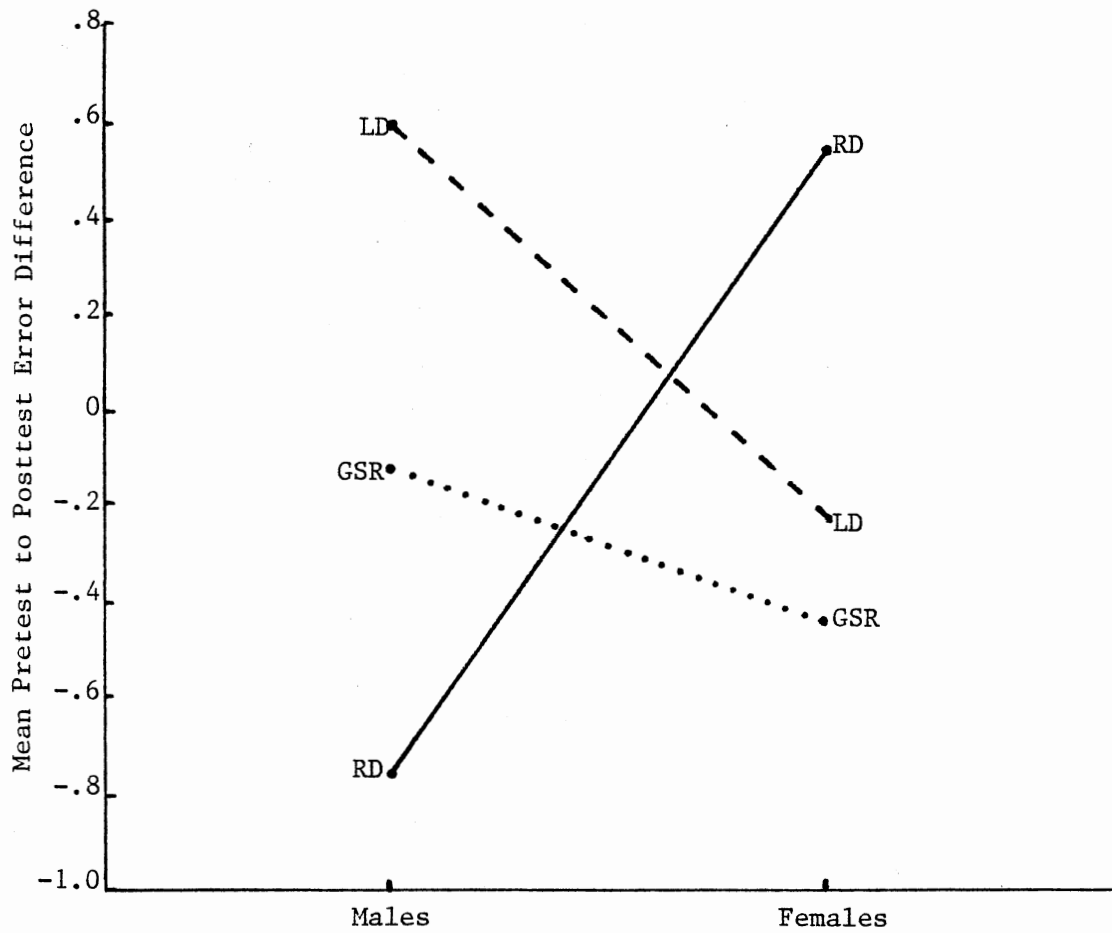
Figure 6.   Group x Sex Interaction on Pretest to Posttest Error
Differences for GSR, LD, and RD Groups

Since the two most extreme means (RD group males and females) differed by only 1.3, all comparisons were found to be nonsignificant by this procedure.

There was a significant main effect for hemisphere of presentation, $F(1,24)=38.45$, $p<.0001$, with left hemisphere presentation showing an increase in mean errors of .983 and right hemisphere presentation a decrease of .833. A significant task by presentation interaction was found, $F(1,24)=71.87$, $p<.0001$ (see Figure 7). The greatest pretest to posttest change was for the spatial/left combination with a mean increase of 2.13 errors. For all other combinations there were decreases in errors. The greatest decrease was for verbal/left (1.67) followed by spatial/right (1.6) and verbal/left (.067). Tukey's procedure for these means showed that all pairwise combinations differed significantly at the .05 level, with the exception of the spatial/right and verbal/left combinations.

The third significant interaction found was group by task by presentation, $F(2,24)=4.08$, $p<.03$ (see Figure 8). The initial planned comparisons involved nine contrasts designed to test Hypotheses 4 and 5 which predicted differences between the EEG groups and control group and between the two EEG groups on pretest to posttest changes in cognitive performance. The contrast of all means for experimental groups against all means for the control group showed no significant difference as a function of this treatment distinction. Further contrasts also showed no significant differences between experimental and control groups for verbal or spatial tasks. The comparisons between the LD and RD groups showed no significant differences for verbal or spatial tasks or for the combined means for task types. Three additional contrasts were performed
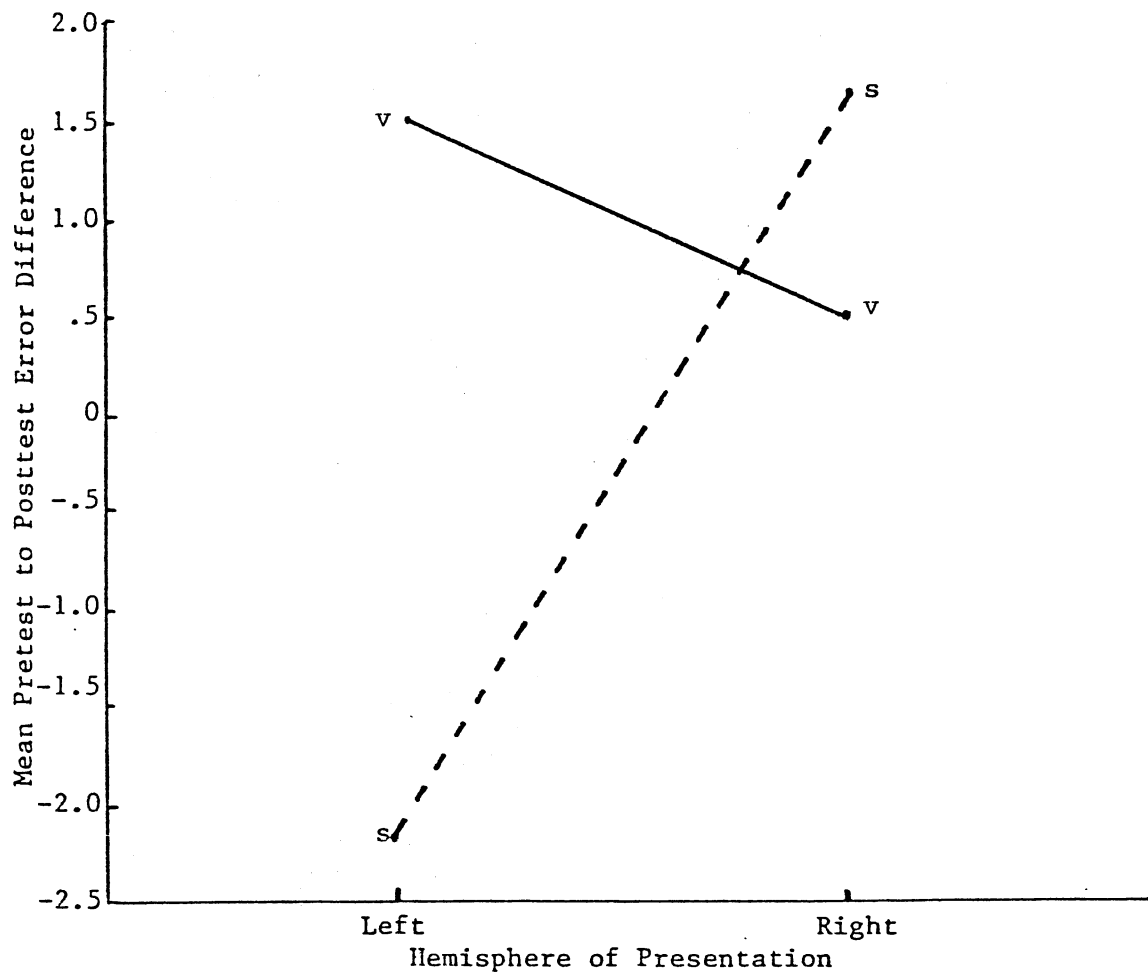
Figure 7. Task x Presentation Interaction on Pretest to Posttest
Error Differences for Verbal (v) and Spatial (s)
Items
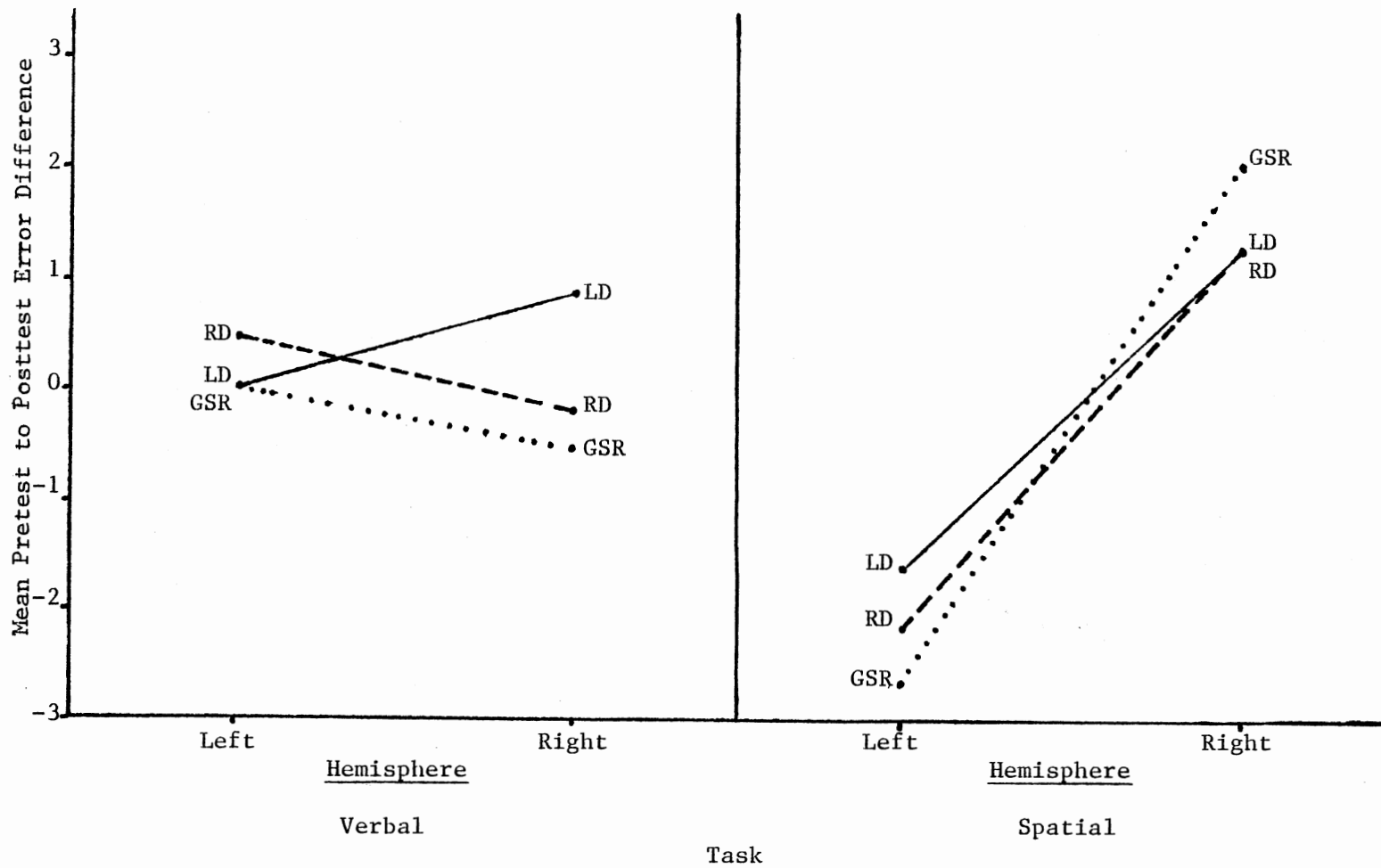
Figure 8. Group x Task x Presentation Interaction on Pretest to Posttest Error Differences for GSR, LD, and RD Groups

in an attempt to determine the cause of the significant interaction. For the combined groups on spatial tasks there was a significant difference as a function of presentation (p<.001), which appears to confirm the main effect for presentation found in the original analysis of variance, but the same contrast for verbal items was nonsignificant. The third contrast showed that the LD group differed significantly from the combined GSR and RD groups on verbal tasks presented to the right hemisphere. This result constitutes a partial confirmation of Hypotheses 4 and 5 in that the LD group showed improvement in accuracy from pretest to posttest, while the GSR and RD groups showed no change.

<center>In-Task EEG Measures</center>

Twelve mixed model ANOVA's were performed on EEG data recorded while subjects were viewing and responding to test items. Separate Group (3) x Sex (2) x Task (2) x Hemisphere of Presentation (2) ANOVA's were performed on pretest and posttest measures of EEG frequency and amplitude in the left and right hemispheres. (Tables X-XVI, Appendix B). Additional ANOVA's were performed on the pretest to posttest differences in each of these measures. A significant sex by task by presentation interaction was found for pretest right frequency, $F(1,24)=4.91$, $p<.0365$ (see Figure 9) and the same interaction approached significance for posttest right frequency, $F(1,24)=4.04$, $p<.0557$. The Tukey's procedure performed on the pretest measures showed no significant differences among the means. However, examination of the graphic representation of the interaction (see Figure 9) shows that the two most extreme means were those for the male/verbal/left and female/spatial/right combinations. On the posttest measures, females' mean frequencies
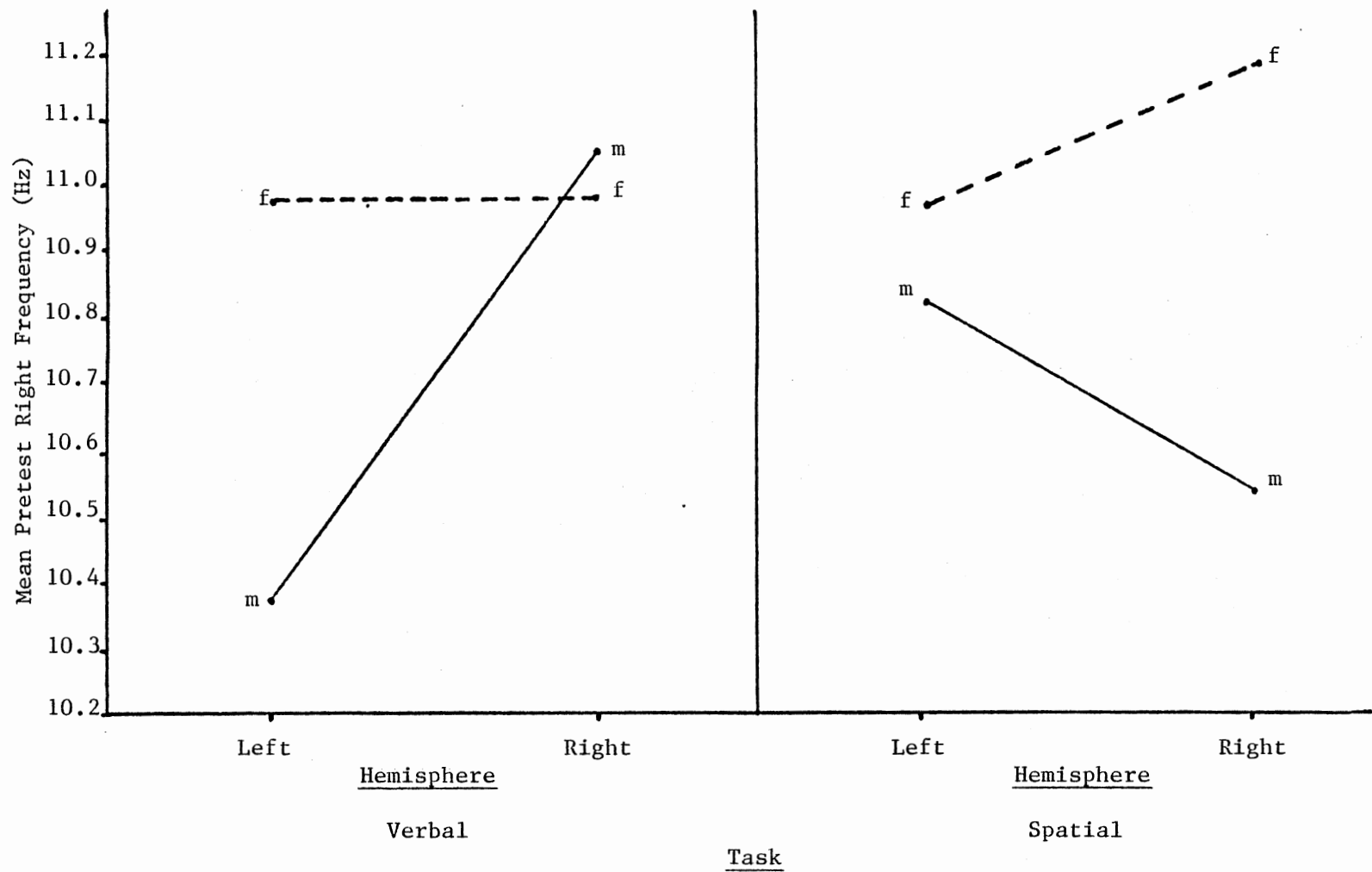
Figure 9. Sex x Task x Presentation Interaction on Pretest Right Hemisphere
Frequency for Male (m) and Female (f) Subjects

were consistently higher than males' across task/presentation combinations, with the greatest difference appearing between males' and females' frequencies in responding to verbal items presented to the left hemisphere. A significant main effect was found for pretest right amplitude measures as a function fo hemisphere of presentation $F(1,24)=9.18$, $p<.006$. The mean right amplitude for items presented to the left hemisphere (59.075 mv) was greater than the mean for right hemisphere presentation (57.475 mv).

Among pretest to posttest differences there were no clearly significant main effects or interactions. On left amplitude differences the effect for hemisphere of presentation reached the probability level $p<.0533$. There was a nonsignificant pretest to posttest right frequency difference interaction as a function of sex and task combinations $(F(1,24)=4.19)$ at the alpha level, $p<.0517$. Males showed a mean increase in frequency of .725 Hz for verbal items and a mean increase of .862 Hz for verbal items. Females had a mean increase of 1.27 Hz for verbal and .878 Hz for spatial items. Tukey's HSD procedure showed a significant difference at the .05 level of probability between males and females on verbal tasks, indicating that females had a greater increase from pretest to posttest in right frequency while processing verbal tasks.

Supplementary Analyses

Because earlier reserach in EEG biobeedback (Murphy et al., 1979) had failed to demonstrate generalization of training effects to the posttreatment testing situation, there was, of course, a reasonable possibility that the same results would be found in the current study.

In order to determine whether or not treatments had an effect upon hemispheric EEG arousal within the training situation, left and right hemisphere frequency and amplitude were recorded for each of five evenly spaced epochs during each of the four training sessions. Separate Group (3) x Sex (2) x Session (4) x Trial (5) x Hemisphere (2) ANOVA's were performed on these in-training measures of frequency and amplitude (Table XVII, Appendix B).

The expectation that unilateral EEG biofeedback causes reduction of frequency in the trained hemisphere leads to the prediction that one or both of the following significant interactions would be found: 1. group by session by hemisphere or 2. group by trial by hemisphere (within sessions). In the above analysis, the group by trial by hemisphere (within sessions) interaction was nonsignificant, $F(32,368)=1.27$, $p<.153$. The group by session by hemisphere interaction approached, but did not reach significance, $F(6,72)=2.16$, $p<.0563$. The graphic representation of these means (see Figure 10) shows a mixture of trends among the treatment groups in hemispheric frequency. The only trend that would appear to match the training prediction would be the decrease in left frequency in the first three sessions for the LD training group. Comparison of the means for this treatment group showed a significant decrease in frequency from session 1 to session 2, $t(368)=4.43$, $p<.001$, and from session 2 to session 3, $t(368)=3.81$, $p<.001$. In session 4, the mean left frequency was significantly higher than in session 3, $t(368)=6.67$, $p<.001$, but significantly lower than in the initial session, $t(368)=3.54$, $p<.001$.

The RD training groups' right frequency changed in the direction opposite the prediction from session 1 to session 2, showing a
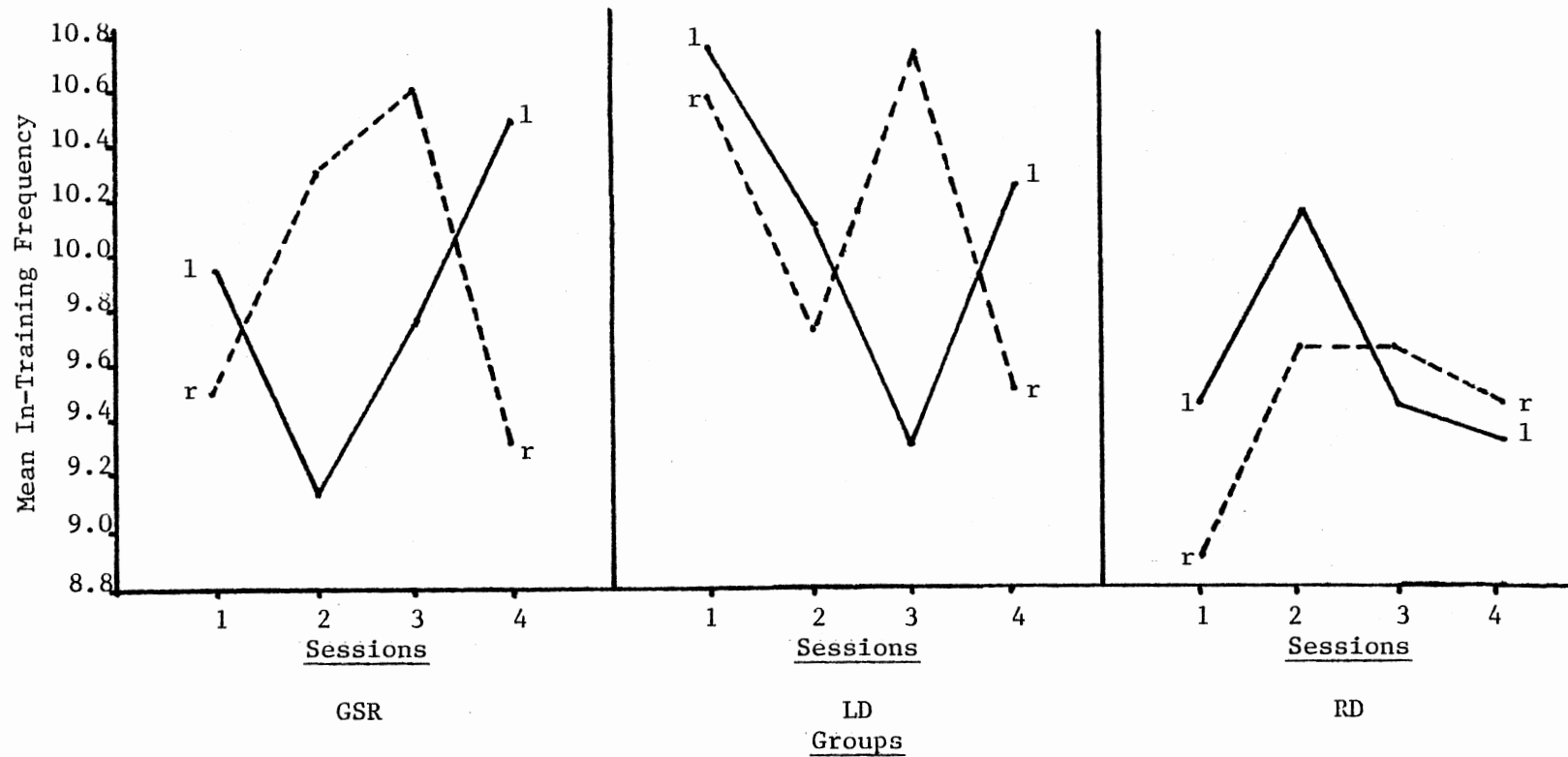
Figure 10.   Group x Session x Hemisphere Interaction on In-Training Frequency
for Left (l) and Right (r) Hemispheres

significant increase, $t(368)=5.01$, $p<.001$. Right frequency for this group did not change significantly from the second session to the third and fourth sessions. One consideration that could seriously effect the interpretation of either of the above results is the difference between the LD and RD groups on frequency measures for both hemispheres in session 1. The LD group's left frequency in the session was significantly higher than the RD group's, $t(368)=9.02$, $p<.001$, and the RD group's right frequency was significantly lower than the LD group's, $t(368)=11.16$, $p<.001$. However, the differences between the LD and RD groups on left and right frequency do indicate a difference in the time course of learned control of EEG for these two types of training. Left-down training appears to have affected incremental learning across sessions, while right-down training seems to have had a positive impact in the first session with no evidence of learned control in later sessions.

In order to gain the maximum possible information from data collected during testing sessions, Pearson product-moment correlation coefficients and significance probabilities were calculated between all possible pairings of the four EEG measures (left and right frequency and amplitude) and two cognitive measures (reaction time and errors) obtained from pretest and posttest. The same calculations were performed for the pretest to posttest differences in these measures (Tables XIX-XXI, Appendix B).

On pretest measures there was a positive relationship between left frequency and right frequency, $r(29)=.5974$, $p<.0005$, indicating that the frequencies in the two hemispheres tended to change in a synchronous manner. There were four significant correlations in the posttest matrix.

Three of those showed relationships between EEG measures that concur with the theoretical expectations for those measures. As with pretest EEG, there was a positive relationship between left and right frequencies, $r(29)=.4982$, $p<.0051$. There were negative relationships between left hemisphere frequency and amplitude, $r(29)=.5199$, $p<.0032$ and between right frequency and amplitude, $r(29)=.5002$ $p<.0049$. On posttest, there was also a significant relationship between reaction time and errors, $r(29)=.3988$, $p<.0291$, indicating that increased (slower) reaction times on the posttest were associated with increased errors.

On pretest to posttest differences in EEG measures there were two significant correlations reflecting much of the same information gained from the two previous correlations. The positive relationship between left and right frequencies, $r(29)=.5358$, $p<.0023$, shows that frequency changes in the two hemispheres tended to fall in the same direction. The negative correlation between left frequency and amplitude changes, $r(29)=.5013$, $p<.0048$, reflects the inverse relationship between frequency and amplitude. There were no significant relationships found between changes in EEG and cognitive measures or between changes in the two cognitive measures. In Chapter IV, the information from the correlational procedures will be integrated and theoretical and practical implications will be discussed.

CHAPTER IV

DISCUSSION

This study proposed to clarify some discrepancies found in previous studies on EEG biofeedback training and the effects of this training upon cognitive performance. The hypotheses were designed to answer the following general questions: Does EEG biofeedback training produce long-term changes in subjects' frequency and amplitude in the different cerebral hemispheres and how do these changes differ from those in subjects receiving an alternate type of biofeedback (GSR)? Do subjects respond faster to verbal and spatial tasks presented to the dominant hemisphere than to similar tasks presented to the nondominant hemisphere? Do different types of biofeedback have differential effects upon these reaction times? Do different combinations of task type and hemisphere of presentation differentially activate the left or right hemisphere and do different types of biofeedback training differentially effect these levels of activation? This discussion will be divided into three sections corresponding to the three types of data addressed in the hypotheses. The fourth section will discuss significant findings in areas not addressed by the hypotheses and the fifth section will examine logical relationships among findings in the different areas and possible practical implications of these findings.

Long-Term Effects of Biofeedback

Due to the high degree of minute-to-minute changeability of the

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physiological variables in this study, the expression "long-term" here refers to a period of days. A previous study (Murphy, et al., 1979) found that subjects were able to change their EEG frequencies in response to biofeedback within training sessions, but that these changes did not generalize from one session to another. The current study found a long-term change in frequency in the EEG left down training group. However, interpretation of this group's long-term decrease in left frequency as training effect was confounded by the finding that their initial baseline on this measure was significantly higher than the other groups'.

The alternative interpretation made possible by this finding is that the LD group's pretest to posttest decrease in frequency was merely a movement back toward the population mean as a function of time and/or habituation. This argument is weakened somewhat by the results of the in-training EEG data analysis that showed an incremental decrease in the LD group's left frequency that was not seen in the other groups. In view of this result, it might be said that the LD group was, in fact, impacted by training, but that the effect was a lowering from a hyper-aroused condition to a normal level.

The design of this experiment does not provide the information needed to determine which of the above explanations is most valid. In future studies, this confounding can be avoided through some fairly simple procedural changes. In the current study, subjects were assigned to treatment groups prior to the recording of any EEG data. If base-lines were obtained for all subjects before assignment to groups, a rank ordering by baseline EEG's could be performed and the groups balanced with equal numbers of high, medium and low EEG subjects. With sufficiently

large n's, analyses could show the presence or absence of training effects upon treatment groups and upon the different rankings of subjects within treatment groups.

A long-term increase in right hemisphere amplitude was found for the GSR training group. In light of the absence of long-term changes in this group's skin conductance levels, this finding could be interpreted as a spurious result. However, one alternative explanation deserves consideration. The increase in right amplitude for this group is assumed to be associated with a decrease in arousal in that hemisphere, the majority of whose neural pathways are connected to the left side of the body that was being trained in the GSR treatment. It might be argued that, since this group showed decreased autonomic arousal across trails in training, they were also learning decreased EEG arousal. The lack of concordance between EEG and GSR measures for baseline and training could be a result of differential sensitivity of these measures under the different conditions in these two situations.

Reaction Time and Error Measures

The stimulus presentation and subject response systems in this study were designed as they were in an attempt to measure the differences in processing time required for verbal and spatial items presented to the dominant or nondominant cerebral hemisphere for each type of item. This portion of the experimental procedure was an adaptation of the procedure used by Gibson et al. (1970). It was predicted (Hypothesis 3) that reaction times for verbal items presented to the left hemisphere and spatial items presented to the right hemisphere would be lower than reaction times for each type of item presented to the opposite

hemisphere. This predicted task by presentation interaction was not found in the pretest data. In the posttest data there was a significant task by presentation interaction, that did confirm the hypothesis. For verbal items, presentation to the dominant hemisphere resulted in faster reaction times than did presentation to the nondominant hemisphere. The same results were found for spatial items presented to the dominant and nondominant hemispheres for that task type. These results on posttest reaction times represent a replication of the Gibson et al. (1970) study in which task dependent differences were found for presentation to both hemispheres. However, no such replication was found on pretest.

This combination of results is difficult to explain in terms of the available data. One possible source of unexplained variation may be the lack of a reliable control upon subjects' eye fixation just prior to the stimulus presentation. The demand characteristics of the experimental situation may have induced some subjects to "cheat" by shifting their gaze in the direction of the anticipated stimulus presentation. The increased variability resulting from this would have the effect of lowering the probabilty of finding a significant interaction. The lack of a significant interaction on the pretest is especially suggestive of the presence of this problem. The presence of this interaction in the posttest, and not in the pretest, could be due to a lowering of sub-jects' achievement orientation or a practice effect at the time of posttest that increased their likelihood of maintaining fixation on the central point.

Another, perhaps more plausible, explanation of this lack of repli-cation on pretest may lie in differences in task difficulty between this study and that of Gibson et al. (1970). The earlier study used word/

nonword decisions for verbal tasks which may require a lower level of processing than syntactical decisions required by this study. For spatial tasks, the development of a large item pool in this study (50) necessitated the use of some moderately complex drawings which may have been more difficult than those in the previous study. Evidence of this is found in the reaction times for each type of item across both testing sessions. The mean for verbal items was 1398 ms and for spatial items the mean was 1193 ms, while the earlier study reported reaction times of less than 1000 ms for both task types. Assuming this higher level of complexity for both tasks, it would follow that reaction time might be a less sensitive measure of cognitive processing efficiency for this item pool and, thus, was unable to detect hemispheric specialization on the pretest.

The analyses of error rate data revealed several interesting relationships between this measure and task/presentation factors. On both pretest and posttest, presentation to the right cerebral hemisphere (left visual hemifield) produced higher error rates for both task types than did presentation of the left hemisphere (right visual hemifield). Since all of the subjects in this study were right-handed, it may also be true that the majority of them had a left hemisphere advantage in terms of visual perception. If so, these main effects for presentation could be explained as being a result of subjects having better perceptual accuracy for items presented to the right visual hemifield.

Significant task by presentation interactions were found on both pretest and posttest. The posttest interaction showed that error rates were lower on spatial items presented to the right hemisphere than to the left, as was predicted in Hypothesis 3. There was no difference in

error rates on verbal items as a function of presentation. This is in contrast to the pretest interaction in which, again, there was no presentation effect on verbal items but error rates on spatial items were higher for right presentation than left. For spatial tasks, this represents a shift as a result of biofeedback or practice (or both) from an effect contrary to prediction to an effect matching prediction. Another study (Mulholland, 1978) that examined responses to EEG found evidence that biofeedback tended to bring extreme scores on physiological measures back toward the group mean. It is possible that the results of this part of the current study are representative of a reduction in variability in physiological mechanisms underlying cognitive performance and, therefore, a normalization of subjects' speed and accuracy in responding.

The correlational analysis of posttest cognitive measures showed a significant positive relationship between reaction time and error rate. Stated another way, when subjects knew the correct answer, they responded more quickly than when they did not know the correct answer. It appears that subjects had some level of awareness that certain items were more difficult for them and took more time to process the stimulus before responding. However, this increased reflectivity did not improve their accuracy.

In the analysis of pretest to posttest differences in reaction times no significant main effects or interactions were found. This indicates that, at least in this study, biofeedback and practice did not impact the speed with which subjects responded to the different combinations of task type and hemisphere of presentation. There was, however, evidence that training had an impact upon accuracy in cognitive

processing. The significant group by task by presentation interaction showed that all groups improved their accuracy in processing spatial tasks presented to the right hemisphere and became less accurate in processing spatial tasks presented to the left hemisphere. Since there were no differences among the groups within these two task/presentation combinations, this must be interpreted as a general training or practice effect. On verbal tasks, training had no effect upon any of the groups' accuracy when these were presented to the left hemisphere. With right presentation, the GSR and RD groups showed no change from pretest to posttest, but the LD group had a significant improvement. It appears, from this, that left-down training facilitates processing accuracy when information must be transmitted across the corpus callosum prior to processing. It may be that this type of training enhances the left hemisphere's receptivity to this transferred information.

In-Task EEG Measures

The final three hypotheses (6, 7 and 8) made predictions about the levels of activation in each hemisphere that would be evoked by the different task/presentation combinations and about changes in these levels produced by different treatments. Hypothesis 6 predicted a task by presentation interaction, across groups, for the four EEG measures recorded at each data point during pretest and posttest. The only significant effect found in these measures was a main effect for pretest right amiplitude as a function of hemisphere of presentation. Presentation of items to the left hemisphere produced higher amplitude in the right hemisphere than did right presentation. Based on the assumption that frequency and amplitude are negatively correlated, this would

indicate that the right hemisphere was more aroused when it was the receptor of either verbal or spatial items relative to its arousal level with left presentation. This result was expected since it is assumed that processing information leads to increased arousal, but it is difficult to explain the absence of significant effects for other EEG measures.

The analyses of the pretest to posttest differences in the four EEG measures were designed to determine whether or not treatments had any effects upon in-task arousal in the different hemispheres and, if so, whether or not these effects varied as a function of task type/hemisphere of presentation combinations. Hypotheses 7 and 8 predicted group by task by presentation interactions demonstrating differential effects of treatment modes on pretest to posttest changes in EEG measures with differences dependent upon task/presentation combinations. Since no such interactions were found, these hypotheses were not confirmed. However, failure to observe such interactions in this study does not mean that such effects could not be found, given certain alterations in experimental design.

Although the measurement epochs for in-task EEG observations were relatively short (one minute), subjects had a period of approximately nine seconds (between the response to one item and the onset of the next) during which they might have engaged in various types of mental activity. If the subjects were, in fact, doing this, the resultant increase in EEG variability would have lowered the probability of finding significant effects on these measures. It is recommended that future studies within this paradigm utilize briefer measurement epochs in order to reduce the likelihood of this increased variability.

The correlational procedures performed on pretest and posttest frequency and amplitude revealed a number of significant relationships, all of which matched the theoretical expectations for these measures. In both test sessions, left and right frequency were positively correlated, which indicates that the momentary levels of arousal in the two hemispheres tend to vary in the same direction. It is not known whether this is a result of one hemisphere "following" the other or if this is indicative of a generalized arousal controlled by the various environmental and internal stimuli that impinge upon the whole person and, therefore, effect both halves of the brain simultaneously. The negative relationships observed between right frequency and amplitude in the pretest and between frequency and amplitude in both hemispheres in the posttest confirm the long-standing assumption that changes in arousal are generally associated with opposite changes in amplitude.

In the correlations of pretest to posttest differences in EEG measures it was found that subjects who had frequency changes in one hemisphere tended to have changes in the same direction in the opposite hemisphere. This indicates that the "following" or generalized arousal phenomenon disucssed above for momentary changes is also present in long-term changes. Also, the negative relationship between hemispheric frequency and amplitude observed in pretest and posttest was found in the pretest to posttest differences in these measures for the left hemisphere. Again, the relationship observed for momentary changes held true for long-term changes.

Effects Not Addressed by Hypotheses

Each of the three treatment groups in this study was counterbalanced

for sex with five males and five females in each. While the hypotheses did not make predictions about sex differences, this sex balanced assignment of subjects to groups allowed for efficient analysis of all data for gender effects. No significant main effects for sex were found, but there were several significant interactions found in the analyses of the various types of data in which sex was a factor.

On pretest reaction time measures, there was a significant sex by hemisphere of presentation interaction. It was found that, with presentation to the right hemisphere, females responded faster than males. A review of sex differences research (Macoby and Jackman) has indicated that one of the most reliable sex differences is in verbal and spatial abilities, with females being more verbally adept than males. Assuming that language is primarily a left hemisphere function, it is interesting to note that females responded more quickly to items presented to the right, spatially dominant, hemisphere. On pretest errors, there were no significant sex effects, indicating that the females' faster reaction times were not accompanied by a decrement in accuracy.

There was a significant group by sex interaction found in the analysis of pretest to posttest error differences. Females in the RD group showed an improvement in accuracy after training, but GSR and LD group females had slight increases in errors. RD group males increased errors while LD group males improved in accuracy and males receiving GSR training showed no change. These results indicate that right hemisphere training produces a decrease in cognitive processing efficiency in males and improves efficiency in females. Left hemisphere training seems to have the opposite effect, but this effect was not as strong as for right training.

On measures of in-task pretest right frequency there was a significant sex by task by presentation interaction. Females showed significantly greater arousal during spatial processing with right presentation than did males during verbal processing with left presentation. Note that this applies only to arousal in the right hemisphere. The high level of arousal in processing spatial/right combinations would be expected since this is presentation directly to the dominant hemisphere and the task is assumed to remain in that hemisphere for processing. With verbal/left processing, the right hemisphere was relatively disengaged in male subjects. The fact that the same was not true for females suggests the presence of a sex difference in the degree of exchange in arousal between the hemispheres. If the assumption is made that females are more verbally adept than males, and therefore more left hemisphere dominant, then it might follow that they would show relatively high arousal (more effort) in the right hemisphere with direct presentation of verbal tasks.

Conclusions and Practical Implications

The results of this study failed to show any changes in baseline EEG measures as a function of biofeedback training. This finding confirms the results of earlier studies that attempted to show this type of effect. The changes observed in EEG measures during training are evidently linked to the mental activities evoked by the task that do not generalize to the relaxed baseline situation. The absence of treatment group effects upon in-task EEG measures also indicates that the effects of training do not generalize to the testing situation, at least in terms of observable levels of cortical electrical activity. However,

changes in cognitive processing efficiency as measured by error rates suggest that the biofeedback may have had behavioral effects. Specifically, LD group males and RD group females reduced their error rates from pretest to posttest while the control group showed no changes. This sex-dependent specificity within treatment groups is considered to be a result of sex differences in cerebral lateralization. (Evidence supporting this assumption is discussed in more detail below.) With further research to determine the exact nature and magnitude of these effects, EEG biofeedback may be shown to be an effective treatment modality for certain cognitive deficiencies.

The most provocative findings in this study involve sex differences in both isolated testing measures and in changes observed after training. In the pretest situation it was found that the sexes differed in speed of response to items presented to the right hemisphere. Males' reaction times were significantly faster than females for right presentation of both task types, suggesting that the right hemisphere in males is more efficient in processing spatial tasks within that hemisphere and in transfering verbal material to the left hemisphere for processing. This may be an indication of sex differences in the nature or degree of cerebral lateralization. There was also a sex difference in the changes in accuracy of responses as a result of training as discussed above. The most direct evidence of sex differences in brain function was found in the in-task EEG measures. It appears that males' and females' cerebral hemispheres are different in the levels of arousal evoked by different tasks. This is evidenced by the significant sex by task by presentation interaction on pretest right frequency (discussed in the above section). There were also sex by task interactions on pretest to

posttest changes in right frequency and amplitude. The relationships among sex, task, and presentation are very complex, but the recurrence of sex as a factor leaves little doubt about the existence of sex differences in cerebral lateralization.

The difficulty in presenting a concise picture of the results of this study is one of the diseconomies of complex experimental designs. However, the results in different areas of the data analyses pose questions that could lead to individual studies designed to answer these questions. Future research in this paradigm should be modified to eliminate the procedural problems pointed out earlier in this chapter. Minor changes in the experimental design could reduce unexplained variability without a significant loss of information and provide clearer conclusions about the hypotheses in this study. Other designs might be used to pursue the issue of sex differences in electrocortical activity and its neuropsychological correlates.

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APPENDIXES

APPENDIX A

LITERATURE REVIEW

LITERATURE REVIEW

Cerebral Lateralization

The brain in higher animals, including man, is a double organ with two distinct cerebral hemispheres connected by a large bundle of nerve fibers called the corpus callosum. The idea that the two hemispheres are specialized to perform different cognitive functions was advanced by Hughlings Jackson as early as 1864. He proposed that the faculty of expression resided in one hemisphere while the faculty of perception resided in the other (Taylor, 1958). Since that time, a variety of neurological evidence has been presented attributing different functions (or lack of them) and varying degrees of specialization to the different hemispheres. In 1926, Henschen hypothesized that all cognitive tasks are carried out primarily by the left hemisphere while, "in every case the right hemisphere shows a manifest inferiority as compared with the left, and plays an automatic role only" (p. 119). In Henschen's view, the right hemisphere was probably a "regressing organ" although "it is possible that the right hemisphere is a reserve organ" (Henschen, 1926, p. 122). By this, he inferred that it served only a compensatory role after left hemisphere lesions. These statements reflected the prevailing view among neurologists at that time. The right hemisphere was considered to be "mute," "minor," "passive," or "subordinate" in relation to the left (Hecaen & Albert, 1978).

After the Second World War, the general belief in left hemisphere

dominance began to yield to one of division of control and functions between the hemispheres. It was effectively demonstrated that certain cognitive impairments occurred with right hemisphere lesions. The consistency of loss of function in these cases, especially in body awareness, spatial orientation, and constructional abilities, impelled reconsideration of the role of the right hemisphere (Hecaen & Albert, 1978; Milner, 1965). In 1963, Hecaen and Anglergues compiled behavioral data on 415 patients with posterior lesions in either the right or left hemisphere. They concluded that the right hemisphere, "appears to play a special role in the appreciation of space and the recognition of faces." In research with normal and brain-damaged subjects it was confirmed that, in the vast majority of humans, the left hemisphere contained the mechanisms for processing verbal material, regardless of the input channel used or the liguistic level of presentation (Hecaen & Albert, 1978).

Animal research published by Myers and Sperry in 1953 showed that, when the corpus callosum was severed, each hemisphere functioned independently as if it were a complete brain. This discovery led to the theory that the corpus callosum serves as a communication network responsible for integration of the operations of the hemispheres in the intact brain. Sperry and his associates pursued this theory in the 1960's with a series of studies on human patients who had undergone commissurotomies for the control of epileptic seizures (Sperry, 1967; Sperry, Vogel & Bogen, 1970; Sperry, Gazzaniga, & Bogen, 1969). These patients retained normal or near-normal levels of language comprehension and use through left hemisphere channels while demonstrating only rudimentary language abilities using right hemisphere channels. The right

hemisphere was shown to be superior in the performance of tasks re-
quiring visual-spatial abilities.

While the results of the split-brain studies are provocative, some
caution must be exercised in attempting to generalize these results to
the normal population. Of special interest to the present study are
those experimental paradigms using EEG recording techniques to demon-
strate cerebral laterlization of function in normal subjects. Several
well-controlled studies compared integrated power measures of specific
wave forms in the two hemispheres while subjects performed verbal and
spatial tasks. Consistent differences in EEG activity were observed as
a function of task type (Galin & Ornstein, 1972; Doyle, Ornstein, &
Galin, 1974; Dumas & Morgan, 1975; Morgan, MacDonald, & MacDonald,
1971). Also of interest in the present study are those paradigms using
word recognition and reaction time to demonstrate greater efficiency in
processing verbal or spatial material presented to sensory channels
leading directly to the hemisphere dominant for processing each type of
material (Klatsky, 1970; McKeever & Huling, 1970; Filbey & Gazzaniga,
1969).

Galin and Ornstein (1972) collected EEG data on subjects performing
a verbal or spatial task, expecting to find evidence of differences in
activity between the dominant and nondominant hemispheres. They quanti-
fied the EEG in terms of power by integrating the raw signal (1-35 Hz)
and expressed asymmetry in activity between homologous leads as a ratio
of right to left power. They hypothesized that the ratio of right to
left hemisphere power would be greater during performance of verbal
tasks than during the performance of spatial tasks. Each subject per-
formed a series of four cognitive tasks, with and without motor output.

The verbal tasks consisted of writing a letter and mentally composing a letter with eyes open and fixated on a central point. Spatial tasks were a modified Kohs block design in which subjects memorized and reconstructed a two-dimensional, geometric pattern and a modified Minnesota Paper Form Board test. The results of this study confirmed the hypothesis of greater right/left power ratios on verbal tasks than on spatial tasks. Significant differences were found in the data from both temporal and parietal leads. The differences between the mental and motor tasks for both sets of data were not significant.

In a followup to the above study (Doyle, Ornstein, & Galin, 1974), a frequency analysis of hemispheric EEG asymmetries was used as the dependent measure. The number of tasks was doubled in both the verbal and spatial categories, while retaining the balance between pure mental and mental/motor tasks. Ratios of power from homologous leads were computed separately for four conventional frequency bands (alpha, beta, theta, and delta). Right/left ratios were found to be significantly higher in verbal than in spatial tasks primarily in the alpha band. The beta and theta bands showed this effect less consistently and the delta band showed no systematic effect of cognitive mode. The results of the analysis of the alpha band alone showed a task-dependence of right/left · ratios two to five times greater than that found in the previous study using whole band power.

Morgan et al. (1971) recorded bilateral EEG alpha activity while subjects performed tasks designed to activate either the left or right hemisphere. They hypothesized that there would be generally more alpha activity in the right hemisphere than the left and that there would be relatively more alpha activity in either hemisphere when it was not

engaged by a task. Their results showed a significant difference in the proportion of right hemisphere alpha, dependent upon the type of task, which is consistent with results of studies reviewed above. However, they also found that there was always more alpha recorded in the right hemisphere than the left, regardless of the task. Similar results were reported by McKee, Humphrey, and McAdam (1973) in an experiment using linguistic and musical tasks to differentially engage the two hemispheres.

Dumas and Morgan (1975) conducted a study of laterality of alpha activity as a function of task type, subjective difficulty, and occupation in adult subjects who were either artists or engineers by profession. Raw EEG data was converted to a laterality score for each experimental condition using a percent difference calculation. The results of the analysis were not significant for occupation or for subjective difficulty. Laterality scores were significantly different as a function of task type. They found lower levels of alpha activity relative to baseline alpha in the hemisphere dominant for the particular task type in which the subject was engaged.

In each of the EEG studies cited above, it was found that the cerebral hemispheres show different types of EEG activity depending upon the type of activity in which a subject was engaged. Verbal tasks produce proportionally higher arousal in the left hemisphere while the right hemisphere is proportionally more aroused by spatial tasks. Significant differences were found between hemispheres using the power measure obtained by integrating all of the conventional frequency bands. However, the much greater task dependency was observed when power was computed for the alpha band alone (Doyle et al., 1974).

While EEG recording is the most commonly used method in studies of cerebral lateralization, another nonobtrusive technique has been used to demonstrate specialization of the hemispheres for different cognitive tasks. In this paradigm, tachistoscopic presentation is used to channel stimuli to either the left or right hemisphere and some measure of the subjects' efficiency in processing these stimuli is recorded for the dependent variable. In several experiments stimuli were presented to the left or right hemisphere and reaction times were recorded (Filbey & Gazzaniga, 1969; Gibson, Filbey, & Gazzaniga, 1970; Moscovitch & Catlin, 1970). The resulting data indicate that reaction time is greater when information must be transmitted across the corpus callosum in order for a response to be made than when such a collosal transmission is unnecessary. The increase in reaction time is attributed to the information transfer.

Filbey and Gazzaniga (1969) and Gibson, et al. (1970) required subjects to make a verbal response to a stimulus presented to either the left or right visual field. Since the left hemisphere generates the verbal response, reaction times were lower when the information was presented to the right visual field than when it appeared on the left. It is assumed that, in the latter case, the information entered the right hemisphere and had to be transferred across the callosum before a response could be made. Similar results were also obtained by Moscovitch and Catlin (1970). In addition, Gibson et al. found that when the verbal response was dependent upon the comparison of two spatial configurations, the initial reaction time difference was reversed. This suggests that spatial information presented to the left hemisphere was transmitted to the right hemisphere for processing and the conclusion was transmitted back to the left for generation of the verbal response.

Klatsky (1970) presented test stimuli to either the right or left visual field during a memory scanning task. When letter stimuli were presented, the subjects indicated whether or not the letter matched one of a previously presented set of letters. When picture stimuli were presented, subjects indicated whether or not the first letter of the name of the pictured object matched a letter in the memory set. It was hypothesized that isolated letters are compared to the memory set in terms of their physical configuration by the right, spatial hemisphere, while pictures are processed by the left, verbal hemisphere. Using reaction time as the dependent variable, the results were interpreted as indicating that the two types of stimuli are processed by different cerebral hemispheres. However, it was not clear from these results whether or not verbal and spatial material were being processed in the manner hypothesized by the experimenter.

Umilta et al. (1974) cited problems with the assumptions derived from visual hemifield experiments, noting that left hemisphere superiority had been observed in some simple spatial discrimination tasks. They did, however, suggest that this might be accounted for by assuming that these simple tasks could be encoded verbally, allowing left hemisphere mediation of the discrimination. If this were true, it might also be assumed that complex spatial tasks could be performed by the left hemisphere if subjects were able to verbally encode all elements of the task. Berlucchi et al. (1979) tested this hypothesis in an experiment in which subjects were required to read the time on a tachistoscopically presented clockface. The number of errors was same for both visual fields, but the speed of the vocal response was higher for the left field, suggesting a right hemisphere dominance for the task.

From this result, they concluded that verbal codability was not sufficient to explain the left hemisphere superiority in some spatial tasks.

Investigating similar questions, Bradshaw et al. (1979) presented three-letter words and nonwords to each visual field for 20 milliseconds. While subjects were unable to identify the words at this length of exposure, their lexical decisions were better than chance and were superior for the right hemisphere. When the exposure time was increased, left hemisphere superiority for identification of words was observed. They suggested that performance of the lexical discrimination task might be mediated by the early "global" stage of visual processing hypothesized by Broadbent (1977), that utilizes "word shape." An alternative explanation might lie in the concept of semantic activation that provides subjects with enough information on which to base a lexical decision. These hypothesis are of interest to the present study because combination of the EEG and tachistoscope/reaction time paradigms could provide in-task measure of brain activation while subjects are performing this type of task. If consistent differences in activation are observed at different scalp locations, this could help to answer some questions about early and late information processing as these relate to cerebral lateralization.

EEG Biofeedback

Biofeedback, in general, is any technique by which a subject's physiological processes (which are not normally attended to or under conscious control) are made known to the subject via some external stimulus. This stimulus, or feedback, may take one of many forms

including a light, a tone, or a verbal report. Properly administered, this information can help the subject to gain voluntary control over internal physiological states. The process of biofeedback may be as simple as monitoring and reporting heart rate or as complex as detecting and analyzing brain waves and transforming the information into a form usable by an unsophisticated subject (Braud et al., 1975).

Biofeedback is a fairly recent discovery, both as a therapeutic technique and a research paradigm. Because the feedback literature emerges from different scientific disciplines, it is difficult to trace the development of this area while doing justice to all the invest- igations involved. In the past fifteen years, animal and human studies have demonstrated the ability of subjects to control heart rate, muscle tension, skin conductance, blood pressure, skin temperature, and elec- trical activity in the cerebral cortex. Shapiro (1976) edits an annual review of research in this area titled, Biofeedback and Self-Control.

A noteable criticism that touched all areas of biofeedback during the early proliferation of the research literature addressed the issue of "conditioning" versus "controlling" autonomic activity. Katkin and Murray (1968) reviewed research on instrumental conditioning of elect- rodermal responses, vascular activity, and heart rate. They cited methodological problems in the area and offered alternative explanations of positive findings. In their final analysis of the paradigm they concluded that instrumental conditioning had been effectively demon- strated in curarized animals. However, they warned that it was not safe to assume at that point, that humans could achieve operant control over these functions.

An important influence on the positive side of this mixed conclusion was the work of DiCara and Miller (1968). This study demonstrated instrumental control of heart rate in curarized rats in avoiding electrical shocks. A review of the literature published by Miller in 1969 described instrumental control of several autonomic responses in animals. Of special interest was his account of Carmona's 1967 attempt to modify brain activity in freely moving cats by stimulating the medial forebrain bundle as a direct reward for changes in brain activity. The success of these experiments led Miller to conclude that, in some cases, direct reward of brain activity may be a more powerful technique for modifying behavior than rewarding of skeletal or visceral responses.

Gaarder (1971), in an attempt to counter arguments such as those of Katkin and Murray, contended that biofeedback is simply a specific instance of the feedback scheme inherent to all operant conditioning models. He stated, "This is a feedback (system) because doing the thing that is desired (i.e. internally initiating an activity) produces external information (in the form of a reward) which is different from the information produced by not doing the desired thing (i.e. from alternative internal states)" (p. 437). Gaarder reasons that a human in a biofeedback experiment is influenced by his own motivation and by the social reinforcement of approval from the experimenter. His evaluation of early work in human biofeedback was that there was ample evidence that humans could control internal states, even without the compelling rewards and aversive stimuli used in animal experiments. Since 1971, numerous studies have confirmed Gaarder's contention and shown humans to be capable of very precise, conscious control over their physiological states.

Of particular interest to the current study are those research efforts aimed at demonstrating the ability of humans to control cerebral electrical activity as measured by the electroencephalograph (hereafter referred to as EEG). Since before World War II, attempts have been made to modify the alpha rhythm in the human EEG through classical conditioning (Jasper & Shagass, 1941; Stern et al., 1961). More recently, it has been shown that humans can learn conscious control of EEG activity through operant conditioning (Kamiya, 1968; Brown, 1970; Nowlis & Kamiya, 1970; Peper, 1972; Hardt & Kamiya, 1976).

An early worker in EEG biofeedback was Joseph Kamiya, whom many reviewers credit with founding this area of study. His first published account of conscious control of EEG alpha was a 1968 Psychology Today article, although one review (Gaarder, 1971) indicates that he had gathered data on this phenomenon in the late 1950's. Another article (Nowlis & Kamiya, 1970) states that Kamiya presented convention papers on this topic as early as 1962. His work is now frequently cited by researchers in the area.

Kamiya's 1968 article describes a study in which subjects' EEG activity was analyzed by digital logic circuits and they were informed of alpha production by a tone. During the first set of minute-long trials, they were instructed to sustain the tone and were informed of the percent of time they were successful at the end of each trial. After five such trials, the task was reversed and subjects were told to suppress the tone for five additional one-minute trials. At the end of 40 alternating task periods conducted over four days, eight of the ten subjects were able to produce or suppress the tone at the request of the experimenter. However, in this article, Kamiya does not report the precise criteria for production or suppression.

In 1970, Nowlis and Kamiya published a more detailed article on the control of EEG alpha through auditory feedback. This study also looked at the subjects' associated mental activity during alpha and non-alpha periods and their ability to produce alpha with eyes opened or closed. All of the 26 subjects produced more alpha during the final suppression trial with less than one hour of training. For 21 of the 26, the amount of alpha was decreased during the final suppression period relative to baseline. Using the sign test, they found the tendency toward change in the desired direction to be statistically significant for both alpha production and suppression.

Analyzing the results for the eyes opened and eyes closed conditions separately, Nowlis and Kamiya found that there was a tendency toward learning in both eye conditions. However, the subjects who were trained with eyes opened were more successful. Whether subject differences or differences in eye condition were more influential in this result could not be determined from these data due to methodological problems in the experiment. It was also difficult to interpret their data on subjective states associated with alpha production and suppression, but there was a strong indication that visual attentiveness was important for alpha suppression in the eyes opened condition.

The above result partially confirms the findings of Mulholland (1965) in an earlier experiment that tested for the occurrence of alpha in subjects with their eyes opened. He projected nonsense syllables before subjects in a darkened or illuminated room whenever alpha occurred, expecting to observe activation of the overall EEG as a result. In neither condition did alpha decrease as greatly as expected and subjects had no trouble producing enough alpha to continue the experiment.

Subsequent studies (Brown, 1970; Sacks et al., 1972) showed the ability of subjects to produce or suppress alpha, at will, with eyes opened. Thus, alpha feedback and attention experiments with eyes opened are feasible according to these results.

Kamiya (1969) reviewed his early developments in EEG biofeedback and discussed subjective reports of mental activities during alpha production. His casual observations of subjects in several studies led him to believe that the high alpha state was a desirable thing to his subjects. He also concluded that subjects who were better at learning to control alpha, especially learning to increase it, were the more introspective ones. Kamiya did not, at that time, attempt to explain the significance of these phenomena, but quantitative research began to appear shortly after that article investigating a broad range of subjective states associated with increased alpha production.

Brown (1970) reported the results of feedback experiments using the three EEG frequency ranges of theta, alpha, and beta to operate lights of three different colors. Subjects were asked to isolate and identify thought and feeling activity that they had used in successfully controlling the lights. The results were controlled for effects of color and for effects of the feedback experience using a control subject group. She found that the choices of descriptors of subjective activities differed significantly between the experimental group who received EEG biofeedback and the control group who sorted only against color. Some of the descriptors found to be significantly related to alpha production were calm, neutral, contemplative, remembering, and drowsy.

In a 1970 article, Peper associated the subjective states of active vigilance, passive relaxing, and drowsiness with the EEG frequency bands

of beta, alpha, and theta, respectively. He assumed that there was a relationship between alpha blocking the giving of oculomotor efferent commands, since in informal experiments subjects learned to control alpha when instructed to use oculomotor commands such as "focus," "blur," and "do not look." Nevertheless, he contended that the high alpha state was associated with passive relaxation and a pleasant, quiet, subjective state without drowsiness. Engstrom, London, and Hart (1970) found that high alpha and hypnosis were typically experiences as very similar subjective states. They were actually able to effect an increase in subjects' scores on the Harvard Group Scale of Hypnotic Susceptibility through alpha training. This suggests the possibility of applying this method to attain different levels of consciousness and in training attentional processes.

Schmeidler and Lewis (1971) compared subjects' pre and post alpha training performance on a mood checklist and the Breskin Rigidity Test. They found that, with increased alpha production, subjects reported significantly more of the moods of subjective states that earlier studies (e.g., Brown, 1970) had found associated with alpha waves. In addition, their subjects showed a significant increase in their prefer-ence for simple sterotypes and quick closure, as measured by the Breskin test. These results were confirmed by Honorton et al. (1972) who found that relatively high alpha was associated with relaxation and a narrow-ing of perceptual awareness.

By 1972, operant control of EEG alpha was a generally accepted phenomenon in the psychological community and several investigators turned their attention to the possibility of localized control of EEG activity. Peper (1972) was able to train one subject to produce alpha

at one scalp location while suppressing it at another location after only two training sessions. He concluded that localized training was feasible and that, with the use of shaping procedures, subjects could learn extremely fine control of EEG patterns at selected locations. Peper also stated that this type of training could have significant applications since these techniques "could be used to enhance the training of subjects with abnormal EEG's and the associated behavioral aberrations; possibly offering treatment through self-control."

Nowlis and Wortz (1973) voiced support for the hypothesis that voluntary control over left/right hemispheric differences in alpha production could be taught with feedback training. They also demonstrated that subjects could increase the ratio of frontal to parietal alpha and then reverse the ratio through auditory EEG feedback training. At the time of testing, some subjects demonstrated differential control even without hearing the feedback tone.

Since 1975, Murphy and his associates at Oklahoma State University have conducted several studies investigating the efficacy of localized EEG feedback training in enhancement of specific cognitive skills. These studies have sought to demonstrate changes in performance on verbal, spatial, and creative tasks as a result of training different levels of activation in the left and right hemispheres. This research is discussed in more detail in the introduction section of this paper.

APPENDIX B

TABLES

TABLE I

DEPENDENT SAMPLES T-TESTS FOR TREATMENT
GROUPS' PRETEST TO POSTTEST CHANGES
ON BASELINE EEG MEASURES

EEG Measure	Mean Change	t Value	p	df
Group: GSR				
Left Frequency	0.019	0.05	NS	9
Right Frequency	−0.706	−1.01	NS	9
Left Amplitude	−0.049	−0.63	NS	9
Right Amplitude	0.182	2.49	p<.0347	9
Group: LD				
Left Frequency	2.909	2.73	p<.0231	9
Right Frequency	0.142	0.17	NS	9
Left Amplitude	0.148	1.46	NS	9
Right Amplitude	0.032	0.48	NS	9
Group: RD				
Left Frequency	−0.409	−0.44	NS	9
Right Frequency	−1.213	−1.42	NS	9
Left Amplitude	−0.024	−0.58	NS	9
Right Amplitude	0.193	1.58	NS	9

TABLE II

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF TREATMENT GROUPS ON PRETEST
LEFT FREQUENCY

Source	SS	df	MS	F	p
Between Groups	532790.067	2	266395.03	4.89	p<.017
Within Groups	1425416.09	27	54473.19		
Total	1958206.600	29			

TABLE III

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF TREATMENT GROUPS (G) AND SEX (S)
ON PRETEST TO POSTTEST
EEG DIFFERENCES

Source	SS	df	MS	F	p
Measure:	Left Frequency				
G	65.148	2	32.574	5.05	p<.0148
S	0.596	1	.596	0.09	NS
GS	34.902	2	17.451	2.71	p<.0872
Measure:	Right Frequency				
G	9.374	2	4.687	0.73	NS
S	9.736	1	9.736	1.51	NS
GS	7.706	2	3.853	0.60	NS
Measure:	Left Amplitude				
G	0.230	2	.115	2.13	NS
S	0.137	1	.137	2.55	NS
GS	0.197	2	.099	1.83	NS
Measure:	Right Amplitude				
G	0.162	2	.081	0.98	NS
S	0.129	1	.129	1.57	NS
GS	0.118	2	.059	0.71	NS

TABLE IV

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF GROUP (G), SEX (S), TASK (T) AND
PRESENTATION (P) ON PRETEST
REACTION TIMES

Source	SS	df	MS	F	p
G	66224.687	2	33112.34	0.10	NS
S	293456.080	1	293456.08	0.86	NS
GS	459718.142	2	229859.07	0.67	NS
T	1317964.800	1	1317964.80	16.69	p<.0004
GT	51170.230	2	25585.12	0.32	NS
ST	98407.041	1	98407.04	1.25	NS
GST	91056.652	2	45528.33	0.58	NS
P	8554.785	1	8554.79	0.41	NS
GP	28867.143	2	14433.57	0.70	NS
SP	122036.652	1	122036.65	5.90	p<.023
GSP	57025.546	2	28512.77	1.38	NS
TP	969.008	1	969.008	0.02	NS
GTP	67233.507	2	33616.75	0.62	NS
STP	14533.203	1	14533.20	0.27	NS
GSTP	32383.683	2	16191.84	0.30	NS

TABLE V

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF GROUP (G), SEX (S), TASK (T) AND
PRESENTATION (P) ON PRETEST
ERRORS

Source	SS	df	MS	F	p
G	0.617	2	0.309	0.21	NS
S	0.075	1	0.075	0.05	NS
GS	4.650	2	2.325	1.57	NS
T	11.408	1	11.408	11.55	p<.0024
GT	1.617	2	0.809	0.82	NS
ST	0.208	1	0.208	0.21	NS
GST	1.317	2	0.659	0.67	NS
P	20.008	1	20.008	13.68	p<.0011
GP	2.817	2	1.409	0.96	NS
SP	0.675	1	0.675	0.46	NS
GSP	4.650	2	2.325	1.59	NS
TP	18.408	1	18.408	35.34	p<.0001
GTP	3.817	2	1.909	3.66	p<.0409
STP	0.208	1	0.208	0.40	NS
GSTP	1.317	2	0.659	1.26	NS

TABLE VI

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF GROUP (G), SEX (S), TASK (T) AND
PRESENTATION (P) ON POSTTEST
REACTION TIME

Source	SS	df	MS	F	p
G	890475.246	2	445237.62	0.91	NS
S	760386.961	1	760386.96	1.56	NS
GS	104487.194	2	52243.59	0.11	NS
T	1218934.104	1	1218934.10	19.82	$p<.0002$
GT	90064.081	2	45032.04	0.73	NS
ST	13574.514	1	13574.51	0.22	NS
GST	264323.901	2	132161.95	2.15	NS
P	24125.852	1	24125.85	1.29	NS
GP	23272.201	2	11636.10	0.62	NS
SP	35.534	1	35.53	0.00	NS
GSP	12776.643	2	6388.32	0.34	NS
TP	833316.667	1	833316.67	21.85	$p<.0001$
GTP	56277.942	2	28138.97	0.74	NS
STP	28449.961	1	28449.96	0.75	NS
GSTP	32515.368	2	16257.68	0.43	NS

TABLE VII

T-TEST VALUES FOR PLANNED COMPARISONS OF
TASK-PRESENTATION INTERACTION MEANS
ON POSTTEST REACTION TIME

Means
Verbal-Left (VL)-------1357 ms
Verbal-Right (VR)------1495 ms
Spatial-Left (SL)------1322 ms
Spatial-Right (SR)-----1126 ms

Comparison	t Value	p	df
VL+SR vs. VR+SL	4.68	$p<.001$	116
VL vs. VR	3.871	$p<.001$	116
SR vs. SL	5.498	$p<.001$	116

TABLE VIII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF GROUP (G), SEX (S), TASK (T) AND
PRESENTATION (P) ON POSTTEST
ERRORS

Source	SS	df	MS	F	p
G	6.317	2	3.159	1.58	NS
S	0.300	1	0.300	0.15	NS
GS	12.350	2	6.175	3.09	p<.0638
T	30.000	1	30.000	20.17	p<.0001
GT	1.050	2	0.525	0.35	NS
ST	0.300	1	0.300	0.20	NS
GST	0.950	2	0.475	0.32	NS
P	30.000	1	30.000	30.90	p<.0001
GP	1.850	2	0.925	0.95	NS
SP	0.300	1	0.300	0.31	NS
GSP	1.550	2	0.775	0.80	NS
TP	38.533	1	38.533	45.56	p<.0001
GTP	2.517	2	1.259	1.49	NS
STP	2.700	1	2.700	3.19	p<.0866
GSTP	1.950	2	0.975	1.15	NS

TABLE IX

T-TEST VALUES FOR PLANNED COMPARISONS OF
TASK-PRESENTATION INTERACTION MEANS
ON POSTTEST ERRORS

Means
Verbal-Left (VL)---------.9
Verbal-Right (VR)------1.0
Spatial-Left (SL)------3.0
Spatial-Right (SR)------.9

Comparison	t Value	p	df
VL vs. VR	0.421	NS	116
SL vs. SR	8.842	p<.001	116
VL+SR vs. VR+SL	6.55	p<.001	116
SL vs. VL+VR+SR	46.53	p<.0001	116

TABLE X

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST TO POSTTEST
ERROR DIFFERENCES

Source	SS	df	MS	F	p
G	4.550	2	2.28	0.70	NS
S	0.075	1	0.08	0.02	NS
GS	24.950	2	12.48	3.84	$p < .036$
T	4.408	1	4.41	1.56	NS
GT	1.217	2	0.61	0.22	NS
ST	0.008	1	0.01	0.00	NS
GST	0.817	2	0.41	0.14	NS
P	99.008	1	99.00	38.45	$p < .0001$
GP	2.717	2	1.36	0.53	NS
SP	1.875	1	1.88	0.73	NS
GSP	10.850	2	5.43	2.11	NS
TP	110.208	1	110.21	71.87	$p < .0001$
GTP	12.517	2	6.26	4.08	$p < .0298$
STP	1.408	1	1.41	0.92	NS
GSTP	3.317	2	1.66	1.08	NS

TABLE XI

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST TO POSTTEST
REACTION TIME
DIFFERENCES

Source	SS	df	MS	F	p
G	805803.35	2	402901.67	2.96	p<.0711
S	109088.73	1	109088.73	0.80	NS
GS	227772.49	2	113886.24	0.84	NS
T	1933.62	1	1933.62	0.01	NS
GT	38014.18	2	19007.09	0.14	NS
ST	38883.60	1	38883.60	0.29	NS
GST	45328.68	2	22664.34	0.17	NS
P	61413.30	1	61413.30	1.18	NS
GP	103746.56	2	51873.28	0.99	NS
SP	126237.02	1	126237.02	2.42	NS
GSP	89488.80	2	94744.40	0.86	NS
TP	777452.91	1	777452.91	10.26	p<.0038
GTP	51331.95	2	25665.98	0.34	NS
STP	2315.29	1	2315.29	0.03	NS
GSTP	119965.28	2	59982.64	0.79	NS

TABLE XII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECT OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST IN-TASK
LEFT FREQUENCY

Source	SS	df	MS	F	p
G	10.918	2	5.459	0.34	NS
S	11.722	1	11.722	0.72	NS
GS	12.501	2	6.251	0.38	NS
T	0.277	1	0.277	2.25	NS
GT	1.361	2	0.681	5.53	p<.0106
ST	0.067	1	0.067	0.54	NS
GST	0.126	2	0.063	0.51	NS
P	0.021	1	0.021	0.17	NS
GP	0.035	2	0.018	0.14	NS
SP	0.020	1	0.020	0.16	NS
GSP	0.230	2	0.115	0.95	NS
TP	0.458	1	0.458	1.19	NS
GTP	0.448	2	0.224	0.59	NS
STP	0.017	1	0.017	0.04	NS
GSTP	0.088	2	0.044	0.11	NS

TABLE XIII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST IN-TASK
RIGHT FREQUENCY

Source	SS	df	MS	F	p
G	38.205	2	19.103	1.46	NS
S	3.362	1	3.362	0.26	NS
GS	12.907	2	6.454	0.49	NS
T	0.031	1	0.031	0.16	NS
GT	0.160	2	0.080	0.42	NS
ST	0.118	1	0.118	0.61	NS
GST	0.826	2	0.413	2.16	NS
P	0.633	1	0.633	1.74	NS
GP	0.093	2	0.047	0.13	NS
SP	0.043	1	0.043	0.12	NS
GSP	0.424	2	0.212	0.58	NS
TP	1.067	1	1.067	2.06	NS
GTP	0.519	2	0.259	0.50	NS
STP	2.548	1	2.548	4.91	$p < .0365$
GSTP	1.968	2	1.968	1.90	NS

TABLE XIV

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON POSTTEST IN-TASK
LEFT FREQUENCY

Source	SS	df	MS	F	p
G	12.485	2	6.243	0.84	NS
S	0.521	1	0.521	0.07	NS
GS	99.730	2	49.865	6.70	p<.0049
T	0.389	1	0.389	1.31	NS
GT	0.355	2	0.178	0.60	NS
ST	0.001	1	0.001	0.00	NS
GST	0.174	2	0.087	0.29	NS
P	0.001	1	0.001	0.01	NS
GP	0.048	2	0.024	0.11	NS
SP	0.135	1	0.135	0.64	NS
GSP	0.602	2	0.301	1.43	NS
TP	0.028	1	0.028	0.07	NS
GTP	0.075	2	0.038	0.10	NS
STP	0.323	1	0.323	0.84	NS
GSTP	0.970	2	0.485	1.26	NS

TABLE XV

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON POSTTEST IN-TASK
RIGHT FREQUENCY

Source	SS	df	MS	F	p
G	10.482	2	5.241	0.33	NS
S	13.210	1	13.210	0.84	NS
GS	68.225	2	34.113	2.17	NS
T	0.059	1	0.059	0.55	NS
GT	0.412	2	0.206	1.91	NS
ST	0.676	1	0.676	6.27	p<.0195
GST	0.508	2	0.254	2.35	NS
P	0.196	1	0.196	1.76	NS
GP	0.312	2	0.156	1.40	NS
SP	0.014	1	0.014	0.13	NS
GSP	0.042	2	0.021	0.19	NS
TP	0.145	1	0.145	0.51	NS
GTP	0.537	2	0.269	0.95	NS
STP	1.150	1	1.150	4.04	p<.0557
GSTP	0.501	2	0.251	0.88	NS

TABLE XVI

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST TO POSTTEST
IN-TASK LEFT FREQUENCY
DIFFERENCES

Source	SS	df	MS	F	p
G	1.928	2	0.964	0.03	NS
S	7.299	1	7.299	0.26	NS
GS	101.509	2	50.755	1.80	NS
T	0.010	1	0.010	0.02	NS
GT	1.481	2	0.741	1.31	NS
ST	0.056	1	0.056	0.10	NS
GST	0.487	2	0.244	0.43	NS
P	0.012	1	0.012	0.04	NS
GP	0.159	2	0.080	0.23	NS
SP	0.051	1	0.051	0.15	NS
GSP	0.434	2	0.217	0.62	NS
TP	0.712	1	0.712	0.63	NS
GTP	0.803	2	0.402	0.36	NS
STP	0.490	1	0.490	0.44	NS
GSTP	1.495	2	0.748	0.67	NS

TABLE XVII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), TASK (T) AND PRESENTATION
(P) ON PRETEST TO POSTTEST
IN-TASK RIGHT FREQUENCY
DIFFERENCES

Source	SS	df	MS	F	p
G	35.251	2	17.626	0.50	NS
S	3.244	1	3.244	0.09	NS
GS	28.028	2	14.014	0.40	NS
T	0.175	1	0.175	0.54	NS
GT	0.860	2	0.430	1.33	NS
ST	1.357	1	1.357	4.19	p<.0517
GST	0.721	2	0.361	1.11	NS
P	0.125	1	0.125	0.30	NS
GP	0.549	2	0.275	0.67	NS
SP	0.008	1	0.008	0.02	NS
GSP	0.202	2	0.101	0.24	NS
TP	1.997	1	1.997	2.50	NS
GTP	2.105	2	1.053	1.32	NS
STP	0.275	1	0.275	0.34	NS
GSTP	1.969	2	0.985	1.23	NS

TABLE XVIII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS OF
GROUP (G), SEX (S), HEMISPHERE (H),
SESSION (D), AND TRIAL (T) ON
IN-TRAINING EEG MEASURES

Source	SS	df	MS	F	p
Measure:	Frequency				
G	818166.107	2	409083.05	1.06	NS
S	378394.567	1	378349.57	0.98	NS
GS	122849.660	2	61424.83	0.16	NS
D	70834.116	3	23611.37	0.21	NS
GD	773891.907	6	128981.98	1.13	NS
SD	323915.242	3	107971.74	0.94	NS
GSD	738507.699	6	123084.61	1.08	NS
T(D)	393495.167	16	24593.45	1.87	p<.022
GT(D)	436499.353	32	13640.60	1.03	NS
ST(D)	110475.273	16	6904.70	0.52	NS
GST(D)	283312.207	32	8853.51	0.67	NS
H	617.767	1	617.77	0.00	NS
GH	43056.980	2	21528.49	0.15	NS
SH	2.901	1	2.90	0.00	NS
GSH	47215.047	2	23607.53	0.16	NS
DH	935251.442	3	311750.48	4.45	p<.0065
GDH	859742.899	6	143290.48	2.04	p<.071
SDH	43092.189	3	14364.06	0.20	NS
GSDH	480973.513	6	80162.25	1.14	NS
HT(D)	111615.807	16	6975.99	0.72	NS
GHT(D)	394920.753	32	12341.28	1.27	NS
SHT(D)	135790.927	16	8486.88	0.88	NS
GSHT(D)	199019.073	32	6219.35	0.64	NS

TABLE XVIII (Continued)

Source	SS	df	MS	F	p
Measure:	Amplitude				
G	0.127	2	0.06	0.00	NS
S	2709.008	1	2709.008	0.90	NS
GS	6725.340	2	3362.67	1.12	NS
D	2403.336	3	801.11	0.86	NS
GD	4251.967	6	708.66	1.25	NS
SD	3272.843	3	1090.95	0.94	NS
GSD	10487.820	6	1747.97	1.23	NS
T(D)	1658.660	16	103.67	0.86	NS
GT(D)	4803.440	32	150.11	1.25	NS
ST(D)	1814.33	16	113.40	0.94	NS
GST(D)	4715.707	32	147.37	1.23	NS
H	12103.101	1	12103.101	5.21	p<.032
GH	5619.847	2	2809.92	1.12	NS
SH	5121.201	1	5121.201	2.21	NS
GSH	5169.647	2	2584.82	1.11	NS
DH	6723.483	3	2241.28	1.46	NS
GDH	13495.460	6	2249.24	1.46	NS
SDH	1662.236	3	554.08	0.36	NS
GSDH	14012.487	6	2335.41	1.52	NS
HT(D)	1726.033	16	107.88	1.10	NS
GHT(D)	3355.827	37	104.87	1.07	NS
SHT(D)	2497.247	16	156.08	1.59	NS
GSHT(D)	3880.733	32	121.27	1.23	NS

TABLE XIX

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS
FOR PRETEST EEG AND COGNITIVE MEASURES

| | Measure | | | | |
	Right Frequency	Left Amplitude	Right Amplitude	Error Rates	Reaction Times
Measure					
Left Frequency	.5974*	−.0225	.1843	.0069	.2846
Right Frequency		−.0589	−.2250	.3001	.1895
Left Amplitude			−.0750	.1444	.0708
Right Amplitude				−.1501	−.1012
Error Rates					−.1657

*p<.0005

TABLE XX

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS
FOR POSTTEST EEG AND COGNITIVE MEASURES

| | Measure | | | | |
Measure	Right Frequency	Left Amplitude	Right Amplitude	Error Rates	Reaction Times
Left Frequency	.4982**	-.5199**	.0252	.0029	.1841
Right Frequency		-. 2291	-.5001**	-.0267	.0791
Left Amplitude			.1391	-.1996	-.3072
Right Amplitude				.1377	-.1689
Error Rates					.3988*

*$p < .05$
**$p < .01$

TABLE XXI

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS FOR
PRETEST TO POSTTEST DIFFERENCES IN EEG
AND COGNITIVE MEASURES

	Measure				
Measure	Right Frequency	Left Amplitude	Right Amplitude	Error Rates	Reaction Times
Left Frequency	.5358*	-.5013*	.1419	-.0061	-.1781
Right Frequency		-.1823	-.3342	.1337	-.3569
Left Amplitude			-.2324	-.2341	-.1034
Right Amplitude				.0634	.1796
Error Rates					.1806

*p<.01

TABLE XXII

ANALYSIS OF VARIANCE SUMMARY TABLE FOR EFFECTS
OF SEX (S), SESSION (D), AND TRIAL (T) ON
IN-TRAINING SKIN CONDUCTANCE LEVELS
FOR THE GSR GROUP

Source	SS	df	MS	F	p
S	31.166	1	31.166	3.20	NS
D	28.365	3	9.455	1.43	NS
SD	7.818	3	2.606	0.40	NS
T(D)	12.225	16	0.764	3.79	$p < .0001$
ST(D)	3.509	16	0.219	1.09	NS

VITA 2

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