THE EFFECTS OF BILATERAL EEG BIOFEEDBACK ON VERBAL, VISUAL-SPATIAL, AND CREATIVE SKILLS IN LEARNING DISABLED MALE ADOLESCENTS

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CHAPTER I

INTRODUCTION

Recent research supports the interpretation that some types of learning disabilities are due to dysfunction at the level of the cerebral hemispheres. Maturational lags, rather than structural alteration or damage, seem to be primarily responsible for this cerebral dysfunction and the accompanying patterns of cerebral arousal (see Appendix A). The success of previous research with normal subjects demonstrating self-control of cerebral electrical activity through EEG feedback, makes this technique a logical focus for research attempts to modify the arousal patterns which characterize the cerebral dysfunctions in learning disabilities. Several studies have used EEG feedback procedures to manipulate the level of cerebral arousal with learning disabled and normal subjects and assessed the effect on various abilities.

Nall (1973) used biofeedback alpha (EEG arousal reduction) training procedures in an attempt to modify the behavior of learning disabled children. The results were assessed by both academic and behavioral indices. She reported specific cases where significant improvement occurred on both measures, but few overall effects. Only reading comprehension scores were significantly higher following alpha training. Interestingly, while the subjects in the control group varied in gains and losses on the behavioral and academic measures, the treatment group subjects consistently exhibited either increments or decrements in both areas at the same time, indicating a synchronization of behavior.

Braud, Lupin, and Braud (1975) employed electromyographic biofeedback to control the hyperactivity of a 6 year-old male. In this paradigm, the electrical activity of the frontalis muscle group was monitored and the subject was trained to reduce the activity or tension level. Both parent and teacher observations indicated an overall improvement in the subject's behavior, and a marked reduction in psychophysiologic symptoms. Significant changes in emotionality also occurred during the course of the relaxation training, with confidence increasing and signs of frustration decreasing. The subject showed dramatic improvement of ITPA and Wide Range Achievement Test scores. Braud et al. interpreted these findings as illustrating the benefits of biofeedback relaxation training with hyperactive subjects, but did not relate them to underlying patterns of cerebral arousal. However, the relaxation, easing of tension, and feelings of restfulness and well being which characterized the muscle tension reduction in this paradigm frequently accompany EEG alpha training.

Murphy and Darwin (1975) investigated the effects of left hemisphere alpha and beta training on learning disabled adolescents. They assessed changes in the affective domain, on achievement tests, and on teacher ratings of academic and socio-emotional behavior. Alpha training was found to enhance self esteem, expressed warmth, and disinhibition. It also specifically enhanced WRAT: Arithmetic subtest scores.

Murphy, Darwin, and Murphy (1977) monitored alpha and beta band density during verbal and spatial tasks. The subjects were learning disabled adolescents who either had Wechsler Performance IQ scores 15 points above their Verbal IQ scores, or had no Verbal-Performance IQ discrepancy. The IQ discrepant subjects produced greater alpha band density (lower arousal) in both hemispheres during verbal and spatial tasks. Apparently, a state of hypoarousal in both hemispheres in-task is typical of learning disabled adolescents who show presumptive evidence of cerebral dysfunction.

Murphy, Lakey, and Maurek (1976) examined the effects of bilaterally divergent EEG feedback training with normal college males. Two treatment groups were trained to enhance alpha in one hemisphere while suppressing it in the other. Pre and post verbal and spatial tasks were administered. The group trained to increase left hemisphere alpha (decrease arousal) produced more variable verbal than spatial changes. Subjects trained to increase right hemisphere alpha produced the opposite pattern. The results were interpreted as providing support for the hypothesis that alpha training increases competence in processing by enhancing plasticity.

These EEG feedback studies indicate that Verbal IQ deficient learning disabled adolescents are characterized by a state of hypoarousal in both hemispheres. In addition, both unilateral and bilateral alpha training resulted in greater plasticity, facilitating or increasing the variability of abilities subserved by the alpha trained hemisphere.

Martindale and Greenough (1973) hypothesized that increments in arousal level would lead to enhanced performance on intellectual tasks and poorer performance on creative tasks. Subjects were given the Remote Associates Test and the WAIS: Similarities subtest under varied ? arousal conditions. As they had predicted, the higher arousal condition appeared to enhance creative performance. Martindale and Greenough concluded that both creativity and intelligence may be correlated with facility for changing the level of arousal.

Martindale and Hines (1975) divided male subjects into four groups on the basis of their performance on the Remote Associates Test and the Alternate Uses Test. Right hemisphere EEG alpha was monitored under basal conditions, while the subjects took creativity and intelligence tests, and while the subjects attempted to enhance or suppress alpha activity. The findings indicate that creativity was connected with a tendency to exhibit a large percentage of basal alpha as the task demanded more divergent thinking (Alternate Uses Test), and a tendency to exhibit differential amounts of alpha on cognitive tasks that demanded both convergent and divergent thinking (Remote Associates Test). This study underscored the associations between creativity and low in-task cortical activation, and between creativity and facility for changing the level of arousal. Martindale and Hines also replicated the findings of Martindale and Armstrong (1974) demonstrating that highly creative subjects were characterized by disinhibition, which Murphy and Darwin (1975) identified as a biproduct of alpha training with learning disabled adolescents.

Working from research which had demonstrated that creativity was associated with certain patterns of cerebral arousal, Whisenant (1976) attempted to manipulate creativity scores through four modes of bilateral EEG feedback training. These modes consisted of either training the hemispheres in opposite directions to differentially increase or decrease in EEG frequency, or training them in the same direction to increase or decrease in frequency. Training effects were demonstrated only on the Remote Associates Test (RAT) where training the hemispheres in the same direction, regardless of increase or decrease in frequency, appeared to be the important factor in improving scores. Differential training produced significant decrements in RAT scores. One training condition was different from the others in terms of in-task EEG power (i.e., a mathematic integration of the electrical power of the EEG which is inversely related to arousal). The right hemisphere up--left hemisphere down training group showed a significant increase in power in both hemispheres. In addition, the direction of right hemisphere training was found to have a differential effect on power during the verbal and spatial sections of the Ideational Fluency test. It was the right hemisphere up - left hemisphere down condition that Murphy, Lakey, and Maurek (1976) found to be correlated with greater verbal score variability and increased plasticity.

In summary, learning disabled adolescents with Verbal-Performance IQ discrepancies favoring the Performance IQ are characterized by a state of hypoarousal and high power in both hemispheres. Paradoxically, ? alpha or down training the left hemisphere, which should further hypoarouse the subject and thus increase the severity of the deficit, has been shown to facilitate the performance of tasks subserved by that hemisphere (Murphy & Darwin, 1975). Equally paradoxical, divergently training the right hemisphere up and the left hemisphere down produced an increase in in-task EEG power in both hemispheres (Whisenant, 1976), and facilitated verbal score variability (Murphy, Lakey, & Maurek, 1976). This divergent training mode thus has potential as a verbal-convergent thinking training procedure. Another mode of EEG feedback training that seems especially appropriate for a learning disabled population is training both hemispheres to simultaneously decrease in EEG frequency. This mode was shown by Whisenant to be an important factor for improving

RAT scores, and thus has potential as a creativity-divergent thinking training procedure.

Research then has demonstrated that differential levels of cortical arousal are correlated with verbal, visual-spatial, and creative indices and that facility in changing these levels of arousal may be the key to successful performance in these areas. There is also some evidence to suggest that the learning disabled lack this facility to shift arousal levels. Bilateral EEG feedback has produced changes in the verbal, visual-spatial, and creative indices of normal college students, but these findings had not been investigated in regard to a learning disabled population. The present study proposed to assess the extent that verbal, visual-spatial, and creative indices could be manipulated in a learning disabled population by bilateral EEG feedback procedures.

CHAPTER II

METHOD

Subjects

The subjects were 24 male adolescents chosen from the population of students served by the Oklahoma Title VI-G Child Service Demonstration Center for secondary learning disabled students. These secondary learning disabled students had been identified by psychoeducational evaluation and had been placed in the resource room at their respective schools. The secondary schools of four rural Oklahoma towns were represented by the sample of subjects. In addition to being identified as learning disabled, the subjects had presumptive evidence of cerebral dysfunction as indicated by Wechsler Verbal IQ scores at least 12 points lower than Performance IQ scores. Only males were selected as subjects because of lateralization differences between males and females, and because of the greater incidence of learning disabilities among males. Parental consent was obtained for the participation of all subjects.

Biofeedback Trainers

The trainers were undergraduate and graduate psychology students who had been instructed in the design of the experiment and equipment, procedures for applying electrodes, conducting of the testing and training sessions, and instructions to the subject.

Trainers received practice on mock subjects until they could apply the six electrodes accurately, quickly, and smoothly. It was necessary to procure the subject's help each time the electrodes were applied. The subject held some of the electrodes in place while the trainer secured them with an elastic headband. Therefore, it was necessary for the trainers to understand how to effectively enlist this help from the subject. Trainers then observed at least one complete session by an experienced trainer. When it was judged that the novice trainer understood each aspect of the session, he was allowed to conduct a session under the observation of an experienced trainer. If the observing trainer judged the novice trainer competent in all phases of a session, the novice trainer was allowed to conduct a session without supervision. A novice trainer, however, was never allowed to conduct his first solo session with a first session subject.

Apparatus

Brainwave biofeedback was given to the subjects via two Autogen 70 feedback units manufactured by Autogenic Systems, Inc. Feedback from the left hemisphere was delivered to the subject in the left side of a set of stereo headphones and right hemisphere feedback was delivered to the right side. In order to minimize confusion, the Autogens were set in such a way that the feedback sound stopped whenever the subject produced the appropriate brainwave. In the case of an increase frequency condition, the upper threshold was set at the subject's baseline and the lower threshold was set at 2 Hertz, the lowest frequency graduation on the Autogen 70. For the decrease frequency condition, the lower threshold was set at the baseline and the upper threshold was set at 20 Hertz, the highest frequency graduation on the Autogen 70. With the former setting, the subject was required to increase brainwave frequency in order to move out of the band and turn the feedback sound off. With the latter setting, the subject was reminded to lower his brainwave frequency in order to move out of the band and turn the sound off.

During the feedback sessions, the Spectrum was set at 7, Integration at 6, Amplitude at 0, with the Scale at XI.

A signal integrator, Autogen 5100, sampled the in-task EEG output of the two hemispheres on a schedule outlined in Table I. The integrator generated a signal corresponding to the area beneath the curve of the raw EEG signal. It therefore served as a measure of the electrical power of the EEG which was inversely related to arousal in the waking subject. A single Autogen 120 served as a prestage for the Autogen 5100 on the posttest due to equipment malfunction on the pretest.

Divergent and Convergent Measures

The present study used two measures of divergent thinking or creative ability that had been shown to have correlations with creative achievements: Wallach's Ideational Fluency (IF) tests, and Mednick's Remote Associates Test--High School Form (RAT). Ideational Fluency items were taken from the work of Wallach and Wing (1969), using those verbal and visual-spatial items which had the highest correlation with the overall score. The verbal IF items called for alternate uses of a common object or for similarities between two common things. The visual-spatial IF items were two sets of drawings, a pattern and a

TABLE I

TESTING ORDER AND HEMISPHERE INTEGRATION SCHEDULE

Test Administered	Phase	Hemisphere Integrated
<u>Session 1</u>		
Ideational Fluency		
Alternate Uses	start to 60 seconds	left
	65 to 125 seconds	right
Line Meanings	start to 60 seconds	left
	65 to 125 seconds	right
Similarities	start to 60 seconds	right
	65 to 125 seconds	left
Pattern Meanings	start to 60 seconds	right
	65 to 125 seconds	left
Remote Associates Test	4 to 5 minutes	right
	6 to 7 minutes	left
	14 to 15 minutes	left
	16 to 17 minutes	right
<u>Session 2</u>		
Durrell Analysis of Reading Difficulties: Silent Reading Paragraphs		
First paragraph	start to 15 seconds	left
Second paragraph	start to 15 seconds	right
Third paragraph	start to 15 seconds	right
Fourth paragraph	start to 15 seconds	left
Minnesota Paper Form Board Test	4 to 5 minutes	right
	6 to 7 minutes	left
	14 to 15 minutes	left
	16 to 17 minutes	right
Wide Range Achievement Test: Arithmetic Subtest		
	start to 15 seconds	right
	20 to 35 seconds	left

continuous line, for which the subject was asked to list all of the things of which the design reminded him. The Remote Associates Test consisted of 20 items in which the subject was presented with three words and asked to write a fourth word that was related to all three. See Appendix B for IF and RAT items and instructions.

In addition, the present study used several measures of convergent thinking as demonstrated through verbal achievement and visual-spatial skills. The Spelling (WRAT-SP) and Arithmetic (WRAT-AR) subtests from the Wide Range Achievement Test (WRAT) were used as verbal achievement measures. Because of the severe verbal handicaps of the subjects, the elementary form of the WRAT, which was designed to assess more basic verbal skills, was utilized rather than the age appropriate form. Another verbal skill, in-context reading ability, was measured with the Durrell Analysis of Reading Difficulty: Silent Reading subtest (DURR-SR). Visual-spatial abilities were assessed with the Minnesota Paper Form Board test (MPFB). The instructions for both the divergent and convergent measures were given orally, the RAT and MPFB being accompanied by written instructions as well.

Procedure

There were two EEG biofeedback conditions: (1) training the right hemisphere to increase frequency while the left hemisphere decreased frequency, and (2) training both hemispheres to decrease in frequency. Each biofeedback subject received eight 21-minute individual feedback sessions with appropriate instructions over a two-month period. There was also a control condition which consisted of pre and posttesting about two months apart without the intervening biofeedback training.

Eight subjects were assigned to each of the conditions such that the pretest means for each group across all tests were matched.

The physical setting for testing and training varied at each of the four schools, but generally involved a private or semi-private setting. The training sessions occurred during the subject's regular resource room period. The control subjects were different only in that they remained in the resource room interacting with the special education teacher rather than receiving the biofeedback training.

Left and right hemisphere temporal-parietal EEG was monitored for in-task power, baselines, and training through four electrodes attached to the subject at positions T3, T4, P3, and P4 with two reference electrodes on the forehead at positions Fp1 and Fp2. In-task power data was collected during pre and posttest administration of the IF, RAT, DURR-SR, MPFB, and WRAT-AR. Frequency and amplitude baselines were taken at the beginning of all testing and training sessions.

While the baseline readings were being taken, the subject was asked to sit straight in the chair with feet on the floor, arms and legs uncrossed, and eyes closed. Amplitude baselines for each hemisphere were taken by opening the lower and upper thresholds of the Autogen 70 to 2 and 20 Hertz respectively, setting the time interval for the percent time meter at 10 seconds, and slowly adjusting the amplitude threshold until the meter read between 40 and 60 percent. This value was recorded and the amplitude threshold control returned to zero. The upper frequency threshold was then lowered and adjusted until the percent time meter read between 40 and 60 percent. This value was recorded as the frequency baseline and used as the starting reference point if taken at the beginning of a training session.

The pretesting was done individually in two sessions separated by several days. The divergent tasks were presented in the first session and the convergent tasks administered in the second session. The time of day was identical for both test periods. The posttest administration followed an identical procedure.

Before the first training session, the subject was familiarized with the feedback sound which was a type of white noise. He was also shown the sound that muscle artifact produces, a crackling sound, plus the noise produced by a misplaced electrode, a buzzing sound. He was instructed to keep the sound off in both ears as much as possible by any internal strategy that worked. If keeping both sides quiet was too difficult, he was told to try to work on one side at a time until he had control of both. The subject was also told that if at any time during the session he was able to keep the sound off easily, the experimenter would move the criterion threshold so as to make it more difficult. If this happened, the subject would hear a burst of feedback sound following a quiet period, and this would mean that he was doing exceptionally well.

After these initial instructions, the baselines were taken and recorded and the thresholds set accordingly. The percent time interval was then set at 100 seconds and the subject was instructed to begin trying to control the EEG feedback by making the sound stay off as much as possible. If at any time during the session and the subject was able to keep the percent time meter below 10 percent for at least 30 seconds, the reference was reset, using the same procedure outlined above for setting the initial frequency baseline.

Throughout the training sessions, the subject was encouraged and supported in his efforts to control the EEG. The subject was informed as to the general nature of the study, but was not told of the differential feedback modes.

Design

Independent Measures

The between subjects variable used in the study was Treatment Condition. Eight subjects were assigned to each of three treatment conditions. There were two biofeedback modes--right hemisphere down, left hemisphere down (RDLD); right up, left down (RULD); plus one control condition (CONT).

Dependent Measures

Amplitude and frequency baseline measures for each hemisphere were taken before each testing and training session. Pre and posttest baseline measures were obtained for all three treatment groups, but because the CONT condition received no EEG feedback, training session baselines were available for only the two biofeedback groups.

Brainwave power measures were obtained during both the pre and posttest sessions. During these tests, the signal integrator was switched back and forth according to the schedule outlined in Table I. In this way, right and left hemispheres, respectively, were sampled during the IF, RAT, MPFB, DURR-SR, and WRAT-AR. Equipment malfunction during the pretest contaminated those data and the pretest power levels were discarded.

The pre and posttest scores on the IF, RAT, MPFB, DURR-SR, and WRAT constituted the third set of dependent measures. The separate items of the IF test, Alternate Uses (AU), Similarities (SIM), Line Meanings (LIN), and Pattern Meanings (PAT), were scored individually. The Spelling and Arithmetic subscales of the WRAT were also scored separately. The DURR-SR was scored for both reading rate and reading comprehension.

Analyses

For frequency and amplitude baseline measures, the data was analyzed by hemisphere across the two biofeedback treatment groups with ten data points (two testing baselines and eight training session baselines), and across all three groups with two data points (pre and posttest baselines).

The power data was analyzed according to the type of task (Divergent, Convergent, or Divergent-Convergent). Each of these three analyses considered the data by the specific test and hemisphere from which the power sample was taken.

The test data was considered in two ways: (1) using change (posttest scores minus pretest scores) as the dependent measure, and (2) using change (pre and post) as a variable with the actual test scores as the dependent measures. The four items of the IF, two subtests of the WRAT, and two measures of the DURR-SR constituted within subjects variables.

Facility for changing frequency and amplitude baselines was compared to pre-posttest change score improvement by calculating Spearman Rank Order Correlations. Facility for changing frequency and amplitude was assessed by subject using the averaged pretest and initial training session baseline and summing the signed deviations from this baseline across the remaining seven training sessions and the first posttest session. Ranks were assigned to these summed deviations for frequency and amplitude for both the right and left hemispheres. These ranks were summed and reranked across frequency and amplitude by hemisphere, and across frequency, amplitude, and hemispheres. Pre-posttest score improvements were calculated by subtracting the pretest score from the posttest score across all tests and subtests. Ranks were assigned by the magnitude of posttest change score. In addition, IF subtest ranks were summed and reranked by verbal and spatial task. The resulting matrices contained seven training baseline factors and 12 change score factors. Three correlational matrices were computed, one for each of the two biofeedback treatment groups and one collapsing across the two biofeedback groups. For the RULD and RDLD matrices, baseline ranks were assigned according to amount of change in the desired direction. Baseline training ranks for the collapsed matrix were assigned by amount of increased arousal.

Table II outlines the various analyses.

TABLE II

ANALYSES WITH NUMBER OF LEVELS FOR EACH VARIABLE

A. TABLE OF VARIABLES

Dependent Variables	Between Subjects Variables	Within Subjects Variables
Baselines (Frequency and Amplitude, Left and Right Hemispheres)	Groups (2 or 3)	Sessions (2 or 10)
Power Divergent (IF and RAT)	Groups (3)	Hemispheres (2) Tasks (5)
Power Convergent (DURR-SR, WRAT-AR, MPFB)	Groups (3)	Hemispheres (2) Tasks (3)
Power (Divergent and Convergent)	Groups (3)	Hemispheres (2) Tasks (2)
Change Scores (IF, RAT, DURR-SR, WRAT, MPFB)	Groups (3)	Tasks (for IF) (4) (for DURR-SR) (2) (for WRAT) (2)
Test Scores (IF, RAT, DURR-SR, WRAT, MPFB)	Groups (3)	Change (2) Tasks (for IF) (4) (for DURR-SR) (2) (for WRAT) (2)

TABLE II (Continued)

Appendix and Table Number	B. Listing of Analyses of Covariance with Number of Levels
	Training Sessions Baselines
C-3	Left Hemisphere Frequency: Group (2) X Sessions (8)
C-4	Right Hemisphere Frequency: Group (2) X Sessions (8)
C-5	Left Hemisphere Amplitude: Group (2) X Sessions (8)
C-6	Right Hemisphere Amplitude: Group (2) X Sessions (8)
	Posttest Sessions Baselines
D-7	Left Hemisphere Frequency: Group (3)
D-8	Right Hemisphere Frequency: Group (3)
D-9	Left Hemisphere Amplitude: Group (3)
D-10	Right Hemisphere Amplitude: Group (3)

Appendix and Table Number	C. Listing of Analyses of Variance with Number of Levels
	EEG Power In-Task
E-11	Divergent: Groups (3) X Subjects (8) X Task (5) X Hemisphere (2)
E-12	Convergent: Groups (3) X Subjects (8) X Task (3) X Hemisphere (2)
E-13	Divergent and Convergent: Groups (3) X Subjects (8) X Task (2) X Hemisphere (2)
	Change Scores
F-14	IF: Groups (3) X Subjects (8) X Items (4)
F-15	RAT: Groups (3) X Subjects (8)
F-16	MPFB: Groups (3) X Subjects (8)
F-17	DURR-SR: Groups (3) X Subjects (8) X Task (2)
F-18	WRAT: Groups (3) X Subjects (8) X Task (2)
	Test Scores
G-19	IF: Groups (3) X Subjects (8) X Pre-post (2) X Items (4)
G-20	RAT: Groups (3) X Subjects (8) X Pre-post (2)
G-21	MPFB: Groups (3) X Subjects (8) X Pre-post (2)
G-22	DURR-SR: Groups (3) X Subjects (8) X Pre-post (2) X Task (2)
G-23	WRAT: Groups (3) X Subjects (8) X Pre-post(2) X Task(2)

TABLE II (Continued)

Appendix and Table Number	C. Listing of Correlational Analyses of Baseline Change X Posttest Improvement with Number of Factors
	<u>Matrix</u>
H-24	RULD Group: Baseline (7) X Test (12)
H-25	RDLD Group: Baseline (7) X Test (12)
H-26	RULD and RDLD Group: Baseline (7) X Test (12)

Hypotheses

1. The two biofeedback groups were expected to show changes across the training sessions in their respective right and left hemisphere baseline frequency and amplitude measures, such that down training in a specific hemisphere would result in a decreased frequency and increased amplitude and up training would produce an increased frequency and decreased amplitude.

2. The two biofeedback groups were predicted to differ from the pre to posttest sessions in their respective right and left hemisphere frequency and amplitude according to the direction trained. No changes were expected for the control group.

3. RDLD training was expected to facilitate performance on creative indices, while RULD training was expected to improve posttest scores on verbal achievement measures.

CHAPTER III

RESULTS

The present study utilized three categories of dependent variables: EEG baselines, EEG power in-task, and test scores. In addition, the EEG baseline and test score data were ordered and considered through correlational procedures. The tables corresponding to each section may be found in Appendixes C to H.

Training Phase

To investigate the differential effects of the training on the recorded baselines, two sets of analysis of covariance were performed with the baseline measures on the pretest as the covariate. One set of four ANACOVAs used the baselines from the eight training sessions as the dependent measure. The other set of four ANACOVAs used baseline data from only the posttest as the dependent measure. In all cases, separate analyses were performed for frequency and amplitude by hemisphere, yielding each a set of four ANACOVAs.

No significant main group effects or group x sessions interaction effects were found in the first set of four ANACOVAs on the training session baseline data. A significant main session effect was observed on the left hemisphere frequency baseline data, $\underline{F}(7,98) = 4.299$, $\underline{p} < .001$. Linear trend analysis of this main session effect showed a definite decreasing linear trend across sessions, $\underline{F}(1,98) = 115.33$, $\underline{p} < .001$.

Graphic representation of this shift is presented in Figure 1. Across sessions, both groups generally decreased in their left hemisphere baseline frequency from one session to the next with the exception of session five where both showed a marked increase. This finding provides evidence of training effectiveness since both groups were being taught to reduce their left hemisphere frequency. For left hemisphere amplitude baselines, however, and for both measures of right hemisphere baseline EEG activity, no evidence of training effectiveness was shown. Given the differential training of the right hemisphere in the two groups, the training sessions data provide no evidence of across sessions differences between the treatment groups on these baseline measures.

In the second set of ANACOVAs on the posttest baselines, significant differences among the three groups in terms of frequency and amplitude from the pretest to the posttest sessions were observed in only one analysis, with a significant main group effect on the left hemisphere amplitude baselines, $\underline{F}(2,20) = 3.0216$, $\underline{p} < .071$. The RULD group had an adjusted posttest mean peak-to-peak amplitude of 51.43uv while the RDLD group had a mean amplitude of 37.73uv, with the CONT group value of 47.21uv falling between the two biofeedback groups. A planned comparison of the two biofeedback group means indicated that these baselines were significantly higher for the RULD group than for the RDLD group, $\underline{t}(20) = 2.376$, $\underline{p} < .025$. Thus, on these baseline measures, the effects of training were manifested in only the left hemisphere, with the differential effects of the training occurring only on the posttest.

Test Phase--Power Measures

To assess the differential effects of the training on arousal,

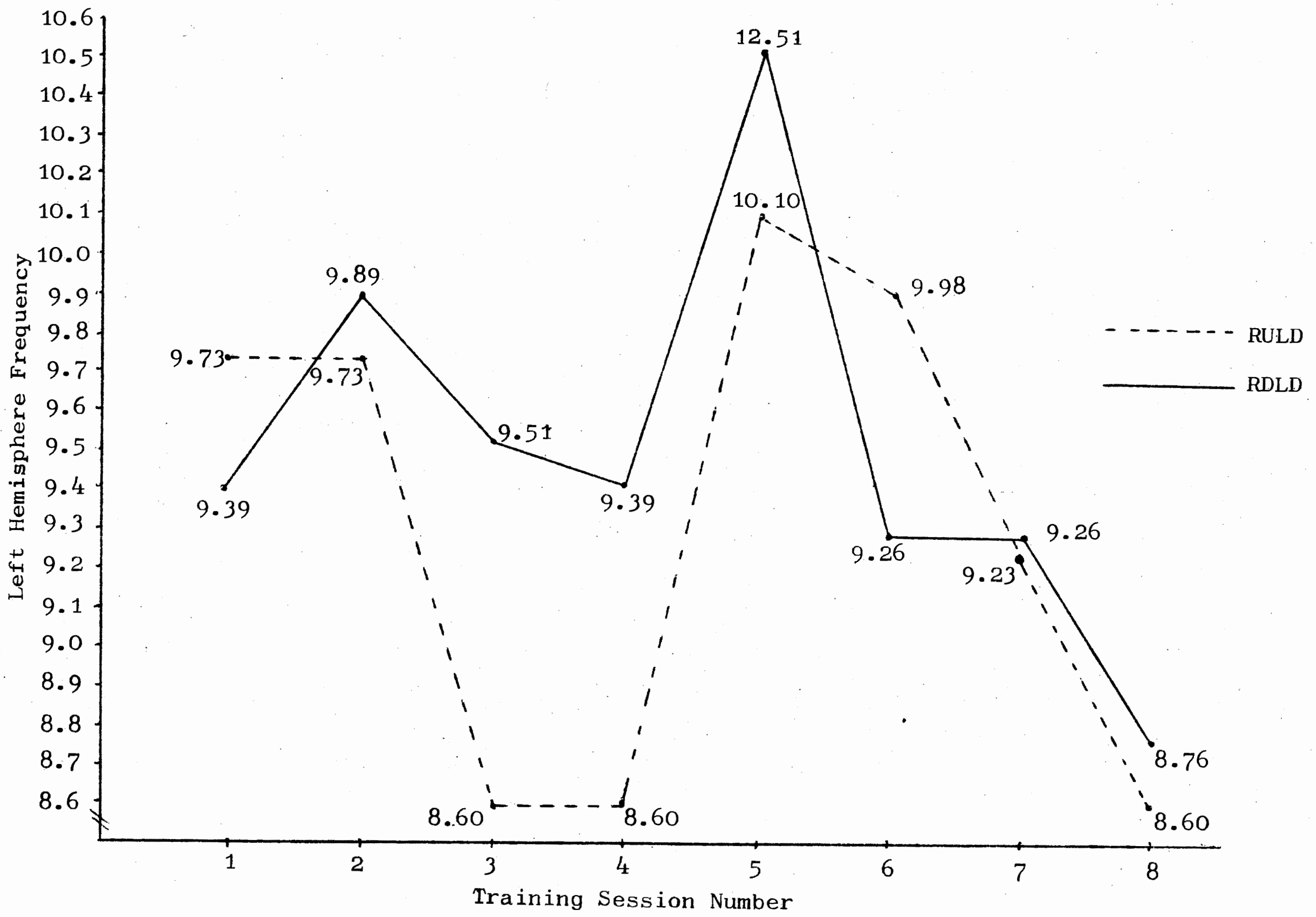

Figure 1. Graphic Representation of the Left Hemisphere Frequency Baseline Main Session Effect

in-task analyses were performed on the EEG power data obtained during the administration of the posttests. These analyses used a mixed design (one between subjects variable: Group; and two within subjects variables: Hemisphere and Task).

Analysis of power data obtained during the divergent tasks (IF and RAT) indicated no significant main effects nor interactions.

The analysis of variance of the convergent tasks (DURR-SR, WRAT-AR, MPFB) power data indicated a significant main effect for task, $\underline{F}(2,42) = 31.5751$, $\underline{p} < .01$, a marginally significant main effect for group, $\underline{F}(2,21) = 3.3245$, $\underline{p} < .07$, and a marginally significant group x task x hemisphere interaction, $\underline{F}(4,42) = 2.4827$, $\underline{p} < .07$. Planned comparison based on the main group effect indicated that the RULD group, $\overline{X} = 9.797$uv/sec, was significantly less aroused in-task than the RDLD group, $\overline{X} = 7.759$uv/sec; $\underline{t}(21) = 2.5714$, $\underline{p} < .01$, with the CONT group showing a mean of 8.909uv/sec. Post hoc investigation of the main effect for task using Tukey HSD revealed significant differences in arousal for all three convergent tasks, with arousal during the MPFB being lower than during the DURR-SR, $\underline{q}(3,42) = 11.1059$, $\underline{p} < .01$, and the WRAT-AR, $\underline{q}(3,42) = 4.0632$, $\underline{p} < .05$. A higher arousal state occurred during the DURR-SR than during the WRAT-AR, $\underline{q}(3,42) = 7.0427$, $\underline{p} < .01$.

Graphic representation of the group x task x hemisphere interaction on the convergent task power analysis is presented in Figure 2. Examination of this interaction reflects unilateral effects for the RULD group, where decreased arousal in the left hemisphere occurred during the MPFB and WRAT-AR, and decreased right hemisphere arousal occurred during the DURR-SR. The RDLD training bilaterally increased arousal during the DURR-SR and WRAT-AR, and unilaterally increased arousal in

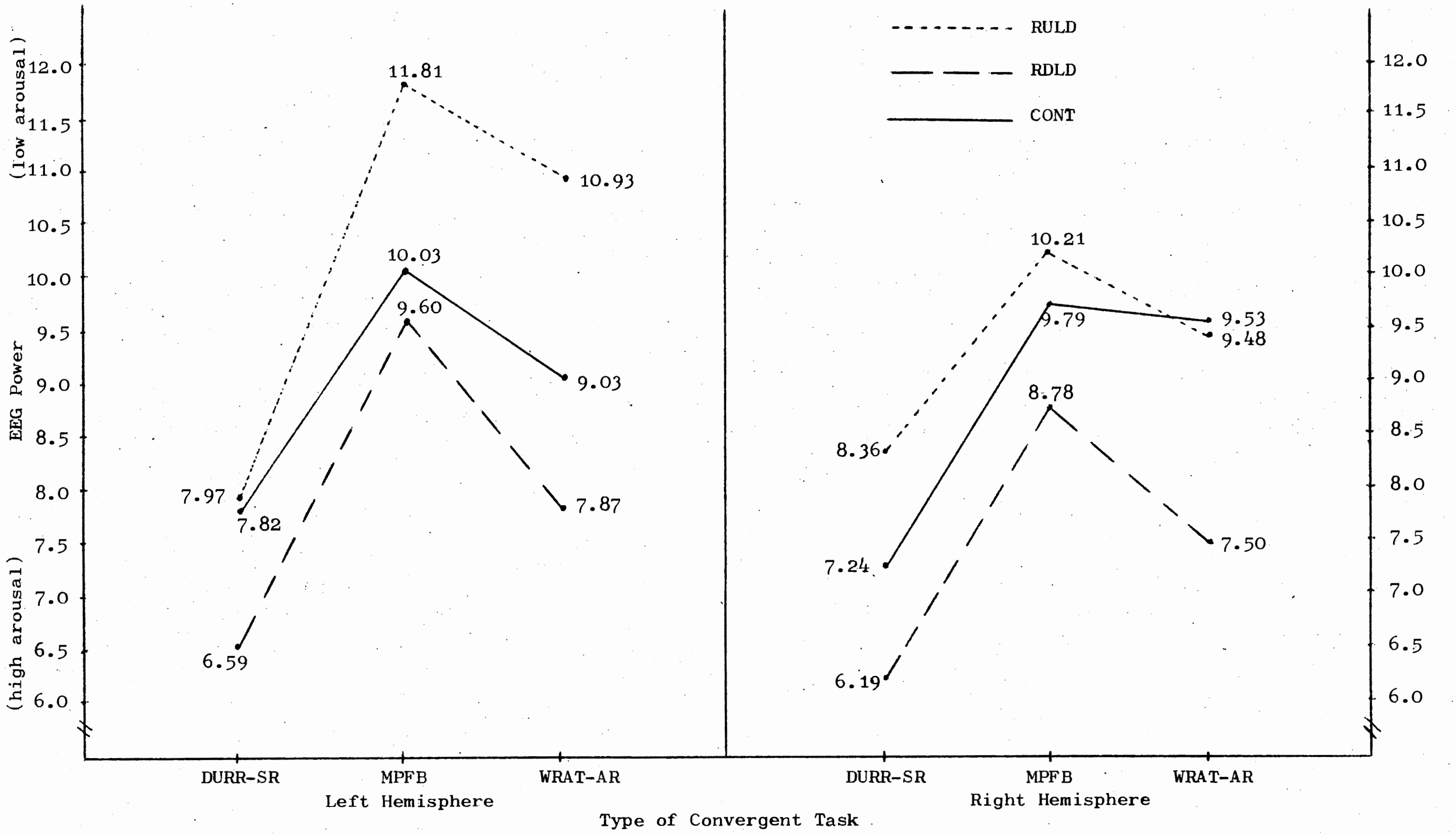

Figure 2. Graphic Representation of the Group x Task x Hemisphere Interaction on the Convergent Task EEG Power Analysis

the right hemisphere during the MPFB. It should be noted that his interaction was significant at only $p < .07$.

The power data were collapsed across individual tests and considered by divergent or convergent task. This analysis of variance indicated a main effect for task with arousal being higher during the convergent tasks, $F(1,21) = 51.4830$, $p < .05$. In addition, there was a marginally significant main effect for hemisphere with the left hemisphere being less aroused, $F(1,21) = 3.0707$, $p < .10$, and a marginally significant group x task interaction, $F(2,21) = 3.2576$, $p < .07$. Post hoc pairwise comparisons of the group x task interaction using Tukey HSD procedures revealed no significant differences between divergent and convergent task arousal for each group.

Test Phase--Test Score Changes

To investigate the effects of training on the divergent and convergent test scores, analyses were performed using change (posttest minus pretest), and using the actual pre and posttest scores as the dependent variables.

Analyses of the change data indicated significant differences between the pre and posttest only on the WRAT-AR. Planned pairwise comparisons between the biofeedback groups and CONT group indicated that the RULD group WRAT-AR scores were significantly more improved than the CONT group scores, $t(21) = 3.24$, $p < .01$. The RDLD group WRAT-AR scores also showed a similar significant improvement effect when compared to CONT scores, $t(21) = 2.11$, $p < .05$. Additional investigation of this effect using t tests for dependent samples on the change scores indicated a significant improvement only for the RULD group, $t(7) = 3.23$,

$p < .02$. This biofeedback group improvement on the WRAT-AR change scores accounts for the marginally significant main pre to posttest effect on the analysis of the WRAT using the actual test scores, $F(1,21) = 4.0405$, $p < .07$.

Analyses of the other actual test scores revealed several significant effects of little practical importance. Significant differences among the IF items occurred, indicating nonequivalence of the measures, $F(3,63) = 21.2784$, $p < .01$. Performance on the RAT was significantly lower for all groups on the posttest than pretest, $F(1,21) = 13.2207$, $p < .01$. The RAT was not a sensitive measure for this population, with most of the subjects obtaining very low percentile scores. Nonequivalence of the pre and posttest RAT forms was also indicated. Grade level scores from the DURR-SR were significantly lower for reading rate than comprehension for all groups, $F(1,21) = 35.3346$, $p < .01$. No significant effects were demonstrated on the MPFB.

Correlational Analysis of Success

Three correlational matrices were computed using rankings of EEG baseline change and test score improvement. A matrix was computed for each biofeedback group, $n = 8$. Another matrix collapsed across the two biofeedback groups, $n = 16$. Each matrix consisted of 84 Spearman Rank Order Correlation Coefficients. By chance, within each matrix, four of these coefficients would be significant at $p < .05$, and one would be significant at $p < .01$. Therefore, to insure a conservative approach to the results of these matrices, only the highest of the significant coefficients exceeding chance expectation were interpreted. On the RULD matrix, four coefficients were significant beyond, $r_s(8) = .643$, $p < .05$;

and three were significant beyond, $r_s(8) = .833$, $p < .01$; but only the highest two were interpreted. Six coefficients were significant beyond $p < .05$ on the RDLD matrix, so again only the highest two were interpreted. On the collapsed matrix, ten coefficients were significant beyond, $r_s(16) = .45$, $p < .05$, thus only the highest six were interpreted. Analyses of these strongest correlation coefficients are summarized by respective matrix:

RULD 1. There was a strong positive relationship between success in producing the desired left hemisphere amplitude increase and improved RAT scores, $r_s(8) = .93$, $p < .01$.

2. There was a strong positive relationship between success in producing the desired right hemisphere amplitude decrease and improved WRAT-AR performance, $r_s(8) = .90$, $p < .01$.

RDLD 1. There was a strong positive relationship between success in producing the desired left hemisphere amplitude increase and improved DURR-SR reading comprehension scores, $r_s(8) = .80$, $p < .05$.

2. There was a strong inverse relationship between success in producing the desired left hemisphere frequency decrease and improved MPFB test performance, $r_s(8) = -.79$, $p < .05$.

COLLAP. Baseline EEG ranks were calculated for the collapsed matrix by the amount of increased arousal, regardless of training modality.

1. Increased right hemisphere frequency led to decreased

performance on the IF (LIN) test of spatial divergent thinking, $\underline{r}_s(16) = -.59$, $\underline{p} < .05$.

2. Decreased right hemisphere amplitude led to increased DURR-SR reading rate, $\underline{r}_s(16) = .54$, $\underline{p} < .05$; and improved WRAT-AR scores, $\underline{r}_s(16) = .48$, $\underline{p} < .05$. See RULD finding #2.

3. Increased arousal in the left hemisphere led to improved performance on spatial convergent thinking as measured by the MPFB test, $\underline{r}_s(16) = .49$, $\underline{p} < .05$. See RULD finding #2.

4. Increased bilateral arousal led to improved WRAT-AR performance, $\underline{r}_s(16) = .53$, $\underline{p} < .05$; but decreased WRAT-SP scores, $\underline{r}_s(16) = -.53$, $\underline{p} < .05$.

CHAPTER IV

DISCUSSION

Three principal hypotheses were investigated in this study. These hypotheses asserted that group effects would occur on EEG measures and cognitive performance as a result of training modality.

The hypothesis that the two biofeedback groups would show changes across the training sessions in their respective hemisphere frequency and amplitude baselines according to the direction of training was only partially supported. No significant differences between treatment groups occurred on their right hemisphere frequency or amplitude baselines. Differences were expected given the differential training of the right hemisphere. Left hemisphere frequency baselines, however, did show a definite decreasing linear trend across sessions for both biofeedback groups. Since the two groups were both trained to decrease their left hemisphere frequency, this finding provides evidence of learning. It is unlikely that this effect was simply due to habituation since the right hemisphere baselines did not show a corresponding trend.

The hypothesis that the three groups would differ from the pre to posttest sessions in their respective frequency and amplitude baselines was also only partially supported. The RULD group was significantly more successful in reducing left hemisphere arousal than the RDLD group. Interestingly, the RDLD group pre-posttest left hemisphere amplitude baselines reflected an increase in arousal. Apparently, divergent training was the critical variable in producing the desired decrement in left hemisphere arousal.

Whisenant (1976) identified several factors which help account for the lack of more consistent baseline effects: many of the baselines were taken during the sessions early in training before the subjects became adept at controlling EEG, the measures were crude and reflected averaging errors, and resting EEG tends to remain stable even though the subject has acquired the ability to produce the desired brainwave changes "at will".

Despite the influence of these factors in the present study, baseline effects did occur in the left hemisphere. The presence of the left hemisphere baseline effects is highly significant when it is noted that Whisenant (1976), using an almost identical methodology, found no baseline effects. Given the methodological similarity, the most apparent difference in the two studies was subject population. Whisenant utilized normal college females, while the present study employed learning disabled adolescent males with evidence of left hemisphere dysfunction. Apparently, there was a relationship between left hemisphere deficits and left hemisphere training susceptibility. One explanation of this relationship is that the left hemisphere in these learning disabled adolescents is less mature and thus more capable of being shaped.

Further evidence of left hemisphere dysfunction affecting EEG parameters is found in the in-task power data. Contrary to Doyle, Ornstein, and Galin (1974), Morgan, McDonald, and Macdonald (1971), and Whisenant (1976) was a finding of lower in-task arousal in the left hemisphere than in the right hemisphere. Previous research by Galin and Ornstein (1972), McKee, Humphrey, and McAdam (1973), and others has conclusively established that the normal state of the brain is a less aroused right hemisphere regardless of the task. While it is possible that this deviation resulted from training the left hemisphere to decrease in arousal, this is unlikely since the control group showed a similar unusual proportion of hemispheric arousal. A more probable explanation is that the deviate in-task EEG arousal pattern is intimately related to the verbal-left hemisphere dysfunction of the subjects. Specifically, arousal has been shown to increase in the hemisphere predominantly involved in processing a given task. The subjects in this study exhibit both left hemisphere hypoarousal and deficits in cognitive tasks associated with left hemisphere function, suggesting that the right hemisphere is doing an inordinate amount of processing to the particular detriment of verbal tasks. These findings then provide support for Gazzaniga (1974) and Satz, Rardin, and Ross (1971) who asserted that learning disabilities are due to a maturational lag in the development of intercortical connections such that the two hemispheres are competing for control.

Group effects also occurred on the EEG in-task power data. The RULD group demonstrated significantly more power than the RDLD or CONT group on the convergent tasks. This increase in in-task EEG power following divergently training the right hemisphere up and the left hemisphere down replicates Whisenant (1976) who attributed its occurrence to training against the grain or natural state of the brain. This explanation is not entirely adequate for the present study though, since the typical in-task brain state of these subjects appeared to reflect a more aroused right hemisphere. Interestingly, Whisenant was training the hemispheres in a pattern most consistent with the in-task arousal state of the learning disabled subjects, and in fact produced the high power-hypoaroused state characteristic of a learning disabled population.

Within the convergent tasks, the highest arousal state occurred during the DURR-SR, followed by the WRAT-AR, and the MPFB test. The demand for continuous concentration and rapid completion of the paragraphs probably accounts for the higher arousal state during the DURR-SR. Reading as tested by the DURR-SR and arithmetic skills as assessed by the WRAT-AR are also the areas of greatest deficit and potential embarrassment for these subjects which may also account for the higher arousal states during these tasks.

A group x task x hemisphere interaction was also observed on the convergent task power analysis. This interaction varied by treatment group in that the RULD training appeared to have unilateral hemispheric effects on the tasks, while the RDLD training produced bilateral shifts in EEG power in-task. These effects are consistent with the differences in training modalities. More importantly though, the group and interaction effects on the convergent task power data indicate that the EEG training impacted on brain states in-task. Given the apparent hypoarousal of learning disabled subjects in-task and the relation of this arousal deficit to verbal performance, evidence that in-task arousal can be modified by biofeedback procedures is highly significant.

All groups revealed a pattern of less arousal during the divergent tasks, supporting the conclusions of Klinger, Gregoire, and Barta (1973), Martindale and Greenough (1973), and Martindale and Hines (1975) who found that creativity or divergent thinking is associated with low in-task cortical activation.

The hypothesis that RDLD training would facilitate performance on measures of divergent thinking, while RULD training would improve scores on convergent thinking tasks was only partially supported. Of the task measures, only the WRAT-AR scores showed meaningful pre-posttest changes, with both the RULD and RDLD groups demonstrating significant improvement when compared to controls. When analyzed against their own scores though, only the RULD group produced significant improvement. Thus RULD training was more successful than RDLD training in producing the desired improvement in convergent performance as measured by WRAT-AR scores. This score improvement replicates Murphy and Darwin (1975) who concluded that left hemisphere alpha training enhanced WRAT-AR scores. While the WRAT-AR improvement is an isolated effect, it is educationally meaningful. Learning disabled subjects typically make little academic progress over a period of several months. Most have acquired minimal arithmetic skills during their school history and often show decrements rather than improvements on WRAT-AR testings. This decline in performance was observed on the CONT group WRAT-AR scores. Thus for a significant improvement to occur during the course of this study is quite remarkable for these subjects and lends strong support to the efficacy of biofeedback procedures.

The lack of treatment group effects on the IF tasks is consistent with Whisenant's (1976) failure to produce treatment group effects on this measure using the same treatment modalities. Whisenant, however, did obtain effects on the RAT which were not replicated in the present study, most probably because the verbal weighting of the measure rendered it insensitive with this learning disabled population.

Despite the marginal support for the three principal hypotheses, correlational analyses of success in producing the desired baseline brainwave changes during training and pre-posttest score improvement indicated that the training had rather specific relationships to test score change. These effects should be interpreted conservatively because of the lack of clear cause-effect information in the correlational statistic, but are of sufficient magnitude to warrant consideration.

Shifts in left hemisphere baseline arousal were accompanied by several test score changes. For the RULD group, left hemisphere amplitude increases (decreased arousal) were related to RAT score improvement. This finding is difficult to interpret since the RAT scores were so low as to suggest that the measure is inappropriate for this verbally deficient population. For the RDLD group, left hemisphere amplitude increases were accompanied by improved DURR-SR reading comprehension scores. Nall (1973) also reported higher reading comprehension scores following alpha training. Given the verbal emphasis of the RAT, both of the above left hemisphere amplitude effects are consistent with Murphy and Darwin (1975) who found that down training the left hemisphere facilitates the verbal tasks subserved by that hemisphere. Increases in left hemisphere frequency (increased arousal) for all subjects were related to improved spatial convergent thinking as demonstrated by MPFB test scores. The presence of a strong relationship between a given hemisphere shift in training session baseline EEG and pre-posttest score change for one group, but not the other, suggests that the direction of training of both hemispheres is an important factor in these effects.

Shifts in right hemisphere training sessions baseline arousal were also accompanied by test score effects. Decreased right hemisphere amplitude (increased arousal) led to improved WRAT-AR performance and increased DURR-SR reading rate for both biofeedback groups. The improvement in DURR-SR reading rate is consistent with research on speed IQ tests which has indicated that increased arousal facilitates rate of any kind.

In addition, increased bilateral arousal led to improved WRAT-AR scores, but decremented WRAT-SP performance. The differential effect of increased bilateral arousal on the two WRAT subtests is difficult to account for. Murphy and Darwin (1975) and Murphy, Lakey, and Maurek (1976) found that arousal reduction training led to improved WRAT-AR scores and improved verbal scores respectively. The WRAT-AR finding thus appears to contradict prior research with a similar population.

While these correlation coefficients give substantive indication of training effects, formulating hypotheses which account for them is difficult because of several factors. First, the relationship of baseline arousal to in-task arousal is often not clear. For example, Whisenant (1976) and Martindale and Armstrong (1974) found that on baseline measures of arousal, highly creative subjects were the most aroused. On measures of arousal in-task though, Martindale and Hines (1975) demonstrated that highly creative performance was associated with low arousal. Thus in approaching the relationship of creativity to arousal, it appears that creativity is associated with high baseline arousal, but low arousal during the creative task. This study's assessment of facility to shift arousal in computing the correlation coefficients reflects neither resting baseline nor in-task arousal and so represents another dimension which is difficult to relate to prior research. In addition, in-task power measures indicate that the hemispheric functioning of these learning disabled subjects is atypical and thus may not exhibit the same arousal changes as hemispheric function in normal subjects who have been the major focus of previous research.

Even though a comprehensive hypothesis cannot be generated on the basis of these results, the correlational analyses of success in shifting arousal during training and test score improvement support the use of both biofeedback treatment modalities as remedial procedures.

As obvious discrepancy in the data is that significant effects occurred in the correlational analyses which did not occur in the analyses of variance, suggesting that uncontrolled individual variables operated in the study which potentially obscured group effects. The motivational level of the subjects during training was a likely source of these individual variations. The subjects exhibited substantial differences in their attitude toward participation and in their overt cooperation. Motivational factors are especially important in a learning disabled population where significant emotional sequelae regarding academic deficits, testing, and success-failure issues predominate. Future researchers might consider training the resident special education teacher to administer the biofeedback procedures as a means of dealing with motivational factors. The resident teacher has typically established more rapport with the student than an outside researcher and thus represents a more potent social reinforcer.

Another possibility accounting for the lack of consistency in the data was individual variation in the rate of acquisition of EEG control. Certainly some subjects would be expected to acquire this skill more rapidly than others. Increasing the number of training sessions might reduce the impact of acquisition rate by allowing all the subjects to experience more practice.

The presence of random error from unstandardized conditions should also be acknowledged. The training and testing of the subjects occurred in six different rooms of four schools under varying conditions, both in terms of physical setting and presence of distracting stimuli. These varying conditions were an unavoidable reality of doing research with these subjects. While the variation of conditions was not ideal, it did represent the spectrum of settings where biofeedback procedures could reasonably be expected to be applied with learning disabled students, and thus represented an appropriate setting for a clinical trial.

CHAPTER V

SUMMARY

Previous research has indicated that differential levels of cortical arousal are correlated with verbal, visual-spatial, and creative indices. Facility in changing these levels of arousal has been suggested as an important aspect of successful performance in these areas. There is also evidence indicating that the learning disabled lack this facility to shift arousal levels. The present study assessed the extent that verbal, visual-spatial, and creative indices could be manipulated in a learning disabled population by bilateral EEG biofeedback procedures. The subjects were 24 male adolescents who had been identified as learning disabled by psychoeducational evaluation, and who had evidence of cerebral dysfunction as indicated by Wechsler Verbal IQ scores at least 12 points lower than Performance IQ scores. Two biofeedback treatments were employed: (1) training the right hemisphere to increase and the left to decrease in EEG frequency, RULD; and (2) training the right and left hemispheres to decrease in EEG frequency, RDLD. There was also a control condition, CONT, that received only pre and posttesting without EEG biofeedback.

The two measures of divergent thinking or creative ability used in this study were Ideational Fluency, IF, test items taken from the work of Wallach and Kogan (1965); and Mednick's Remote Associates Test, RAT, High School Form. Convergent thinking or verbal achievement was assessed by the Wide Range Achievement Test, WRAT, Spelling and Arithmetic subtests; and the Durrell Analysis of Reading Difficulties: Silent Reading Paragraphs subtest. Visual-spatial abilities were assessed through the Minnesota Paper Form Board, MPFB, test.

EEG feedback training produced baseline changes in left hemisphere arousal across training sessions and from pre to posttest. Apparently, there was a relationship between left hemisphere cognitive deficits and left hemisphere baseline training susceptibility, suggesting that this hemisphere was less mature and more capable of being shaped.

Other evidence of left hemisphere dysfunction affecting EEG parameters was found in the in-task power data where, contrary to previous findings, the left hemisphere was less aroused in-task than the right hemisphere. One explanation of this effect was that the right hemisphere was doing an inordinate amount of processing to the particular detriment of verbal tasks.

The RULD group exhibited greater EEG power during the convergent tasks than the RDLD or CONT groups, replicating previous research. Power was greater during the divergent tasks for all groups. The presence of group and interaction effects on the power data indicated that EEG training had impacted on brain states in-task as well as on baselines.

On the convergent tasks, RULD training resulted in significant improvement on WRAT Arithmetic scores. No group differences were observed on the measures of divergent thinking.

Shifts in arousal during training were correlated with several test score changes. Decreases in left hemisphere arousal were accompanied by RAT improvement in the RULD group and improved Durrell reading comprehension for the RDLD group. These findings support previous research suggesting that left hemisphere arousal reduction training facilitates the verbal tasks subserved by that hemisphere. The variation of this effect by group indicates that the direction of training for the right hemisphere was an important factor. Increases in right hemisphere arousal were accompanied by improved WRAT Arithmetic performance and decremented spatial divergent scores. Bilateral training baseline arousal was accompanied by improved WRAT Arithmetic scores, but lower WRAT Spelling scores.

The presence of significant effects in the correlational analyses when these did not appear in the analyses of variance and covariance was discussed in terms of individual variables of motivation and rate of acquisition of EEG control.

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APPENDIX A

LITERATURE REVIEW

I. Cerebral Dominance

A variety of neuropsychological evidence indicates that the hemispheres of the human brain are specialized to perform different cognitive functions. Specifically, the left hemisphere serves as the locus of verbal, language, and analytical capacities, while the right hemisphere is instrumental in visuo-spatial, relational, synthetic, and Gestalt-type abilities (Atkinson & Egeth, 1973; Doyle, Ornstein & Galin, 1974; Galin & Ornstein, 1972; Hartlage & Green, 1973; Humphrey & McAdam, 1973; Kershner & Kershner, 1973; Rosenthal, 1973). This lateralization of cognitive functions has been demonstrated in clinical studies with commissurotomized, hemispherectomized, and lesion patients, and in experimental paradigms with normal subjects utilizing intracarotoid Amytal injections, EEG recording techniques, and performance differentials in tasks involving bilateral presentation of stimuli (Doyle et al., 1974; Dumas & Morgan, 1975; Galin & Ornstein, 1972; Witelson, 1974).

Of primary interest to this study are the experimental paradigms demonstrating laterality of function through EEG recording techniques. These studies sought to determine if there were electrophysical differences between the hemispheres when performing verbal or spatial tasks.

Galin and Ornstein (1972) studied EEG asymmetry in normal subjects during a series of four cognitive tasks. Two of these, writing a letter and mentally composing a letter with eyes open and fixated, were classified as primarily verbal, while the other two, the Modified Kohs block design and the Modified Minnesota Paper Form Board test, were designated as spatial. Recordings were made from the left and right temporal and parietal areas, and the ratios of average power (1-35 Hz) in homologous leads were computed. They found that this ratio (right over left) was greater during verbal than spatial tasks, indicating that the left hemisphere was proportionally more aroused by the verbal tasks and the right hemisphere proportionally more aroused by spatial tasks.

Doyle et al. (1974) extended the above analysis of electrophysical hemispheric asymmetry to include additional cognitive tasks, a neutral task, and a refinement of analysis. In this study, language and arithmetic tasks were expected to engage primarily the left hemisphere, while spatial and musical tasks were expected to engage the right hemisphere. Again, the ratio (right over left) was significantly higher in the verbal-arithmetic tasks than in the spatial-musical tasks. While at no frequency was the power proportionately larger in the hemisphere engaged primarily in the task, the shifts in ratio between the tasks were two to five times larger in the alpha band (8-13 Hz) than in whole band power. These results were interpreted to indicate that the cognitive mode is reliably reflected in patterns of EEG lateral asymmetry, especially in the alpha band.

Galin and Ellis (1975) recorded flash evoked potentials and background EEG from left and right temporal and parietal leads while subjects performed verbal and spatial tasks. They reported that "overall power and peak amplitude characteristics of evoked potential asymmetry reflect the lateralization of cognitive processes, but not as consistently as the concomitant asymmetry in EEG alpha power" (p. 48).

Dumas and Morgan (1975) also employed measurement of the alpha band of the EEG as the dependent measure in their study of laterality. They assert that measuring the alpha rhythm is especially appropriate for electrophysical research of cognitive functions because: it can be used on normal subjects, is minimally obtrusive, and attends to changes that occur while cognitive processing is taking place. The results of their study replicated those previously cited. There was alpha suppression relative to the total amount of alpha in the hemisphere dominant for a particular task.

Morgan, McDonald, and Macdonald (1971) used a similar paradigm to record EEG alpha activity bilaterally during tasks designed to activate either the left or right hemisphere. Their findings, while consistent with those previously noted, indicated that there was always more alpha recorded in the right hemisphere, regardless of the task. The same pattern of results was replicated by Galin and Ornstein (1972) and McKee, Humphrey, and McAdam (1973).

In addition to the functional asymmetry of left and right hemispheres demonstrated in the above studies, Kershner and Kershner (1973) cited R. Sperry as providing evidence that interaction between the two hemispheres is required for high level complex thinking and success in advanced academic tasks.

Both cerebral dominance and interaction are best conceptualized as developmental processes rather than as states. Brown and Jaffe (1975) stated that the notion of cerebral dominance must be qualified to mean "dominance for what function at what age under what conditions of testing" (p. 107). They asserted that cerebral dominance is a continuous process evolving throughout life. As evidence, they cited numerous studies which verify the shift from plasticity to specificity of neurological function with increasing age. This developmental shift is not surprising given the enormous structural, electrophysiological, and biochemical changes the brain undergoes in its maturation, and the correlation of these brain growth phases with developmental milestones in motor, somatosensory, and language functions (Satz, Rardin, & Ross, 1971). An excellent example is the motor performance speed reported by Denckla (1974) where the leveling off of speed after the five-to-seven year age range was quite similar to the curve for brain growth itself.

II. Learning Disability

Learning disability is viewed by Satterfield and Dawson (1971) as being a single aspect of a more complex symptom pattern, minimal brain dysfunction (MBD), beginning early in life and characterized by impairments in perception, conceptualization, language, memory, and control of attention, impulse, or motor function. Another related combination of symptoms also included in the term MBD is the hyperkinetic syndrome. This aspect of MBD is specifically characterized by an abnormally high level of motor activity, a short attention span, low frustration tolerance, aggressive and impulsive behavior and, often, specific learning problems. Rosenthal (1973) suggested that these diagnostic categories are largely a matter of orientation:

> These speculations may as well start with the orientation that the learning disabilities are the clinically noted, functionally expressed problems which are managed by professionals involved in the care (educational, psychological, medical) of these youngsters. Many often profound, secondary emotional disturbances may occur as sequelae of these disabilities. The minimal cerebral dysfunctions are, in most cases, the primary neurophysiological and neuropsychological states that underlie such functional problems. An example is the syndrome of hyperactivity-distractibility with decreased attention span (p. 291).

The developmental laterialization of cerebral function has logical applications to the area of learning disabilities. As Kershner and Kershner (1973) stated:

> It follows that if something interferes with the development of hemispheric asymmetry or if there is a neurological disturbance

> localized in one hemisphere, problems in general behavior and academic tasks could be expected to follow (p. 392).

Verifying the relationship between learning disabilities and impairment of cerebral development has become an increasingly important focus of research.

Rourke (1975) provided an excellent review of studies investigating neuropsychological explanations of learning disabilities. Starting from the premise that

> When mental retardation, emotional disturbance, sensory deprivation, or cultural or instructional factors have been excluded as pertinent etiological considerations, cerebral dysfunction can be presumed to be responsible for the learning deficit (p. 911).

Rourke cited the following findings:

(a) The attentional deficits of learning disabled children mirrored those of children with known brain damage, such that the deficit was more characteristic of younger children and subsided about the time of puberty (Czudner & Rourke, 1970, 1972; Rourke & Czudner, 1972).

(b) When divided into groups on the basis of the presence or absence of lateralized motor deficits, the pattern of psychological test performance of older learning disabled children was quite similar to that exhibited by adults with well documented lateralized cerebral lesions; the patterns of younger learning disabled children were much less consistent (Reed & Reitan, 1963; Reitan, 1955; Rourke, Yanni, MacDonald, & Young, 1973).

(c) Older learning disabled children with specific patterns of Verbal IQ - Performance IQ discrepancies on WISC, behaved in a manner quite similar to that of adults suffering cerebral dysfunction, while younger learning disabled children did not exhibit the same clear patterns of abilities and deficits (Rourke, Dietrich, & Young, 1973; Rourke & Telegdy, 1971; Rourke, Young, & Flewelling, 1971).

(d) Performances of older learning disabled children on the Trail Making Test were quite similar to the patterns of performance of brain damaged adults (Reitan & Tarshes, 1959; Rourke & Finlayson, 1975).

Wiig and Semel (1975) also cited studies where the performance of learning disabled adolescents were characteristic of adult aphasics with left temporal, parieto-occipital, or parieto-occipital-temporal lesions. Satz et al. (1971) noted that the pattern of deficits in dyslexic children was similar to that of adults with left hemisphere damage. Rosenthal (1973b) suggested that dyslexics can be divided into two groups on the basis of phonic or Gestalt weakness, indicating dysfunctional left or right hemispheres, respectively.

While these studies taken together support the interpretation that learning disabilities are due to dysfunction at the level of the cerebral hemispheres and that developmental aspects are crucial in brain-behavior relationships, no studies have documented any structural alteration or damage to the cerebral hemispheres in learning disabled children. This presents a problem in attempting to relate patterns of deficits in learning disabled children to those of brain injured adults through a hemispheric disturbance model. The concept of maturational lag has been advanced by Denckla (1974), Satz et al. (1971), Thompson (1973), Zurif and Carson (1970), and others as a partial resolution of this problem and as a possible mechanism combining the concepts of dysfunction and development. According to the maturational lag hypothesis, the pattern of deficits observed in learning disabled children resembles the behavioral patterns of chronologically younger normal children. Several studies have provided support for this conceptualization. Satz, Friel, and Rudegeair (1974), in a three-year longitudinal study, reported that later dyslexia could be reliably predicted from earlier developmental measures of nonreading skill.

Satz et al. (1971) demonstrated that deficits in visual motor integration, which have an early ontogenic development, are more likely to be observed in younger learning disabled children, while deficits in language and formal operations, which have a later ontogenic development, are more likely to be observed in older learning disabled children. This age discrepant pattern of deficits was confirmed by the Rourke studies. Zurif and Carson (1970) concluded that both dichotic listening and handedness data suggest that dyslexia could be related to a maturational lag in the lateralization of language mechanisms.

Research reported by Reed (1968) points to an age discrepant pattern of deficits for learning disabled children on the WISC. In attempting to differentiate good and poor readers, Reed found that younger dyslexics exhibited inabilities to perceive and express visuo-spatial relations, while older dyslexics were characterized by deficits in verbal abstractions. This data suggests that Verbal IQ scores should be higher than Performance IQ scores in younger learning disability children, and that the opposite pattern would be reflected in the scores of older learning disabled children. This shift in Verbal-Performance IQ discrepancy has been confirmed in longitudinal studies of learning disability children (Murphy, 1976).

It is interesting to note that the vast majority of learning disabled children are males, who maturate at a slower rate than girls (Satz et al., 1971) and lag behind girls in the development of left hemisphere dominance for speech (Kimura, 1967).

Semmes (1968) suggested that the maturational lag observed in the symptom pattern of learning disabled children is due to delays in the lateralization and differentiation of motor, somatosensory, and language functions subserved by the left hemisphere. Gazzaniga (1974) asserted that the lag takes the form of a poorly developed central control system, such that the two hemispheres are competing for control. Accordingly, Satz et al. (1971) cited Geschwild (1968) as stating that those zones which have prominent intercortical connections, necessary in the mediation of more complex language and crossmodal integration skills, are the last to myelinate. Kershner and Kershner (1973) also indicated that hemispheric crossintegration deficiencies are a possible cause of learning difficulties. Denckla (1974) presented data indicating that girls might develop adequate interhemispheric connections at an earlier age than boys, again providing a rationale for the maturational lag hypothesis and the relative preponderance of learning disabled males. Denckla also asserted that

> Preliminary findings implicating faulty inter-hemispheric integration in children with developmental dyslexia have recently emerged from EEG and perceptuo-motor studies (p. 738).

Thus, both hemisphere specific and interhemispheric maturational lags have been proposed as inherent in learning disabilities. Satz et al. (1971) pointed out that remedial efforts can facilitate learning in spite of maturational lags; the success of these remedial programs apparently depending on the plasticity and responsiveness to change of the central nervous system.

III. Learning Disability and Arousal

The close and often synonomous relationship of learning disability and hyperkinesis make recent psychophysiological research with hyperkinetic children especially relevant to an examination of learning disability.

Satterfield and Dawson (1971) compared basal skin conductance (SCL), nonspecific GSRs, and specific GSRs during two experimental sessions with hyperkinetic children and matched controls. They had hypothesized that the symptom pattern of the hyperkinetic children is due to excessive neural excitation or increased arousal level, and that this higher arousal level would be revealed through physiological comparisons. Contrary to their predictions, the hyperkinetic group had lower basal SCL, smaller amounts of nonspecific GSRs, and smaller magnitudes of specific GSRs, revealing that they were underaroused. Satterfield and Dawson interpreted the results in terms of a lowered excitability of the midbrain RAS. They suggested

> ... that the increased amount of motor behavior seen clinically is secondary to lowered levels of RAS excitation, and represents an attempt on the part of the patient to increase his proprioceptive and exteroceptive sensory input (p. 196).

Satterfield and Dawson also point out that the low level of RAS excitability explains the paradoxical effect of stimulant drugs in producing a calming effect on the behavior of hyperkinetic children.

The hypothesis of underarousal in hyperkinesis suggested by data from Satterfield and Dawson (1971) and a replication by Satterfield, Cantwell, Saul, and Yusin (1974) is given additional support by recent EEG arousal research. Grünewald-Zuberbier, Grünewald, and Rasche (1975) studied spontaneous EEG activity and EEG arousal reactions in hyperactive and nonhyperactive children. The EEG was measured in three reaction time experiments. They found that the hyperactive subjects showed a lower degree of EEG activation in periods free from stimulation as indicated by higher alpha and beta amplitudes, more alpha waves, and a smaller number of beta waves. In addition, the hyperactives exhibited shorter arousal responses and longer latencies in reaction time. These results were interpreted as indicating lower levels of physiological activation and reactivity in hyperactive children.

It is especially interesting to note that Satterfield and Dawson's (1971) lowered excitability of the midbrain RAS is consistent with reports of EEG slowing associated with hyperkinetic syndrome found in a number of studies. This slowing is apparently fairly frequent in the MBD symptom complex as a whole and learning disabilities in particular. Burnett and Struve (1974) stated:

> A recent well controlled study has affirmed earlier suggestions that posterior slowing and positive spiking are encountered more often in MBD. Under-achieving school children in general, and mild underachievers in particular, manifested more slowing and positive spiking. The phenomena of temporal slowing and epileptiform patterns were related to different types of intellectual disability. Similarly, Smith has found positive spiking to be associated with a specific brain dysfunction: impaired verbal-symbolic functioning (p. 491).

Muehl, Knott, and Benton (1965) found that slowing and positive spiking were frequent EEG abnormalities in their investigations of reading disabled subjects.

The importance of slowing in the EEGs of both learning disabled and hyperkinetic subjects is that it is indicative of cerebral immaturity in many persons (Hess, 1966), suggesting the presence of a maturational lag in both syndromes. The presence of positive spiking is no less significant. Muehl et al. (1965) report that this pattern is almost exclusively seen in normal subjects in drowsiness and sleep. Thus, it is possible to conceptualize an underarousal of the midbrain RAS based on slow wave activity and positive spiking occurring not only in hyperkinesis, but also in learning disability, and indicating a lag in cerebral development. Many writers feel that both reported EEG abnormalities and disturbed behavior have immaturity as the common denominator (Freeman, 1967).

IV. Biofeedback

Biofeedback is a fairly recent technique which involves monitoring a subject's physiological processes and then reporting these processes to the subject by means of a tone or a light. The feedback of such information allows the subject to gain voluntary control over his internal physiological states (Braud et al., 1975).

Practical therapeutic effects for biofeedback procedures have been demonstrated in self control of blood pressure, heart rate, skin temperature, muscle-tension, and cerebral electrical activity. These findings are reviewed in the annual, Biofeedback and Self Control, edited by Shapiro.

Of primary interest to the present study are reports of attempts to modify the appearance of the alpha rhythm in the EEG record. Nowlis and Kamiya (1970) reported that a number of studies have demonstrated that subjects can learn to control their alpha rhythm through an auditory feedback loop. In addition, "Kamiya (1962, 1967, 1968) has shown that subjects can learn to control both the amplitude and frequency of alpha, depending on how the feedback apparatus is set up" (Nowlis & Kamiya, 1970, p. 477).

Nowlis and Wortz (1973) asserted that several studies give tentative support to the hypothesis that voluntary control over left-right hemispheric differences in alpha production can be taught with auditory feedback training. In their own study, Nowlis and Wortz established that subjects could increase the ratio of frontal to parietal alpha and then the reverse through auditory EEG feedback training. At the time of testing, some subjects demonstrated differential control even without hearing the feedback tones.

Differential control of left-right hemisphere alpha production was demonstrated by Peper (1972). In this study, EEG alpha was monitored, and the subjects were trained to have ON-OFF control over the left and right hemisphere. Peper concluded that the demonstrations of voluntary differential EEG control have significant applications since these techniques "could be used to enhance the training of subjects with abnormal EEGs and the associated behavior aberrations--possibly offering treatment through self control" (p. 263).

V. Creativity

Attempts have been made in recent years to isolate a cognitive dimension called "creativity" from the conventional realm of general intelligence. Guilford (1957), in theorizing on the general scheme of the intellect, divided the thinking factors into three general groups: cognition, production, and evaluation. The production-thinking factors are further subdivided into convergent and divergent processes:

> Thinking must at the same time converge toward one right answer; the significant type of thinking involved has been called "convergent" thinking. With other productive thinking factors and their tests, thinking need not come out with a unique answer; in fact, going off in different directions contributes to a better score in such tests. This type of thinking and these factors come under the heading of "divergent" thinking. It is in divergent thinking that we find the most obvious indications of creativity (p. 112).

The divergent aspect consists of the qualities of fluency, flexibility, and originality. On the basis of factor analytic studies, Guilford (1971) reported that within these three qualities are 24 distinct divergent thinking abilities. The convergent thinking aspects include verbal, numerical, perceptual, visualizing, reasoning, and closure abilities. Guilford (1971) summarized his approach to creativity and intelligence asserting:

> Creative talent is not a single, broad ability parallel to but distinct from another single, broad variable of "general intelligence." Intelligence itself is composed of numerous abilities, and creative performance draws upon very large numbers of them for different purposes and on different occasions, more uniquely upon abilities in the categories of divergent thinking production and transformation (p. 86).

Wallach and Kogan (1965) and Wallach (1970) found that Guilford had placed too diffuse a set of operations in the creative category. Wallach and Kogan subscribed to a variation of the associational conception of creativity proposed by Mednick (1962). Mednick defined the creative thinking process as "the forming of associative elements into new combinations which either meet specified requirements or are in some way useful" (p. 221). Wallach and Kogan attempted to quantify the concept by emphasizing the total number and uniqueness of the associations.

These definitions bear a great similarity to the factor of ideational fluency proposed by Guilford (1957) as an aspect of the divergent thinking domain. Guilford identified ideational fluency as the ability to produce rapidly a succession of ideas meeting certain meaningful requirements. The key differences between the ideational fluency definitions were Wallach and Kogan's emphasis on quality as well as quantity of response and Guilford's emphasis on rapid performance. While Guilford (1971) criticized Wallach's lack of emphasis on time constraints, research by Whisenant (1976) using Wallach's items indicated that scores do not change appreciably as time progresses within the testing situation. Interestingly, Wallach (1970) found that ideational fluency was the only one of Guilford's divergent thinking factors that demonstrated both independence from the convergent thinking domain and coherence within itself, the two necessary conditions for claiming an empirically separable divergent thinking domain. The present study will employ Wallach and Kogan's conceptualization and tests of ideational fluency.

Wallach and Kogan (1965) isolated an ideational fluency dimension distinct from general intelligence in a study with 151 fifth-grade children. They were concerned with the generation of five types of associates: instances, alternate uses, similarities, pattern meanings, and line meanings. Creativity was assessed through two time unlimited variables: the number of unique responses produced, and the total number of responses produced. Intellectual abilities were assessed through the WISC, the School and College Ability Tests, and the Sequential Tests of Educational Progress. The findings indicated that the creativity and intelligence measures are relatively independent of each other, specifically: (a) the correlation between creativity and intelligence measures for the sample as a whole are quite low; (b) the 10 creativity indices are highly related among themselves; (c) each of the 10 creative measures is highly reliable; (d) the 10 intelligence indices are highly related among themselves; and (e) each of the 10 measures of intelligence is highly reliable. Wallach and Kogan concluded:

> Creativity as herein defined - the ability to generate many cognitive associates and many that are unique - is strikingly independent of the conventional realm of general intelligence, while at the same time being a unitary and pervasive dimension of individual differences in its own right (p. 65).

Wallach and Wing (1969) validated the ideational fluency concept by showing it to be predictive of nonacademic achievement in leadership, arts, writing, and science, in a study of 503 incoming freshman students at Duke University. Measures of ideational fluency similar to those utilized by Wallach and Kogan (1965) and questions pertaining to the students' involvement and success in various nonacademic pursuits were employed.

Bartlett and Davis (1974) also validated Wallach and Kogan's battery of ideational fluency tests on a college population. They reported that the correlations indicate that the battery does predict real creative behavior of college students.

Mednick (1962) approached the isolation of an associational concept in a different manner. His widely used measure of creativity, the Remote Associates Test (RAT) was based on "providing stimulus elements from mutually remote associative clusters and having the subject find a criteria-meeting link which combines them" (p. 227). Mednick selected verbal associative habits as being reasonably familiar to almost all individuals in the American culture. Among these were words like: bed-bug, pool-hall, hound-dog, whole-wheat, chorus-girl, kill-joy, and red-hot. The test items consisted of three words drawn from such mutually remote associative clusters. Mednick reported that the RAT has been demonstrated to predict creativity as assessed by supervisor's ratings, student performance, and associative behavior.

Guilford (1971) and Wallach and Kogan (1965) asserted that the RAT is more strongly related to convergent rather than divergent production. Martindale (1975) acknowledged the dependence of the RAT on intelligence factors, but maintained that it is a valid measure of creativity. A complete rationale for the use of the RAT as a creative test was provided by Mednick (1962) and Martindale and Greenough (1973).

Dimond and Beaumont (1974) reported using an association test to examine the role of hemispheric function in the creative process. In their investigation, four-letter words from the Kent-Rosenoff Word Association Test were visually presented to one or the other hemisphere, and the subjects were asked to provide their associations as rapidly as possible. While the response latency was the same for both hemispheres, the associations produced by the right hemisphere were more varied and less common. Dimond and Beaumont interpreted the greater variability and ingenuity of the right hemisphere responses as indicating the greater participation of the right hemisphere in the creative aspects of thought. This is consistent with Robert Ornstein's (1972) conceptualization that the right hemisphere operates in a primary process manner, while the left hemisphere operates in a secondary process manner.

Green, Green, and Walters (1970) investigated the relationship of creativity and cortical arousal. They demonstrated a link between: (a) low arousal EEG alpha-theta patterns and hypnogogic imagery, and (b) hypnogogic imagery and creativity. Morgan et al. (1971) also reported a relationship between lower arousal states and vivid imagery and fantasy.

Klinger, Gregoire, and Barta (1973) measured EEG alpha during six types of cognitive tasks. They found that the divergent thinking tasks, Imagine, Suppress, and Search, produced a high incidence of alpha, while the convergent thinking tasks, Concentration and Choice, blocked alpha.

An important series of studies investigating creativity and cortical activation have been conducted and reported by Colin Martindale. These studies are cogently reviewed by Martindale and Hines (1975). The studies indicated that creativity could be due to low levels of cortical activation, accounting for creativity related traits such as unfocused or broad attention, preference for novel stimuli, disinhibition, and oversensitivity. Also suggested is a tendency toward variability in level of activation, which Martindale and Hines identify as consistent with Kris' (1952) hypothesis that creative subjects have facility for regression in service of the ego; that is, shifting from secondary process (left hemisphere, analytic thought) to primary process (right hemisphere, dreamlike mentation) cognition.

APPENDIX B

IDEATIONAL FLUENCY AND REMOTE ASSOCIATES TEST INSTRUCTIONS AND ITEMS

INSTRUCTIONS FOR THE IDEATIONAL FLUENCY ITEMS

(Presented orally)

Alternate Uses: At the top of this page you will see the word CORK,(CHAIR). You are to list as many uses as you can for a CORK. These can be unusual or common uses, but list as many uses as you can. Don't worry about spelling or handwriting. Please number the uses that you write down. Do you understand what you are to do? Ready, begin.

(The subject was then allowed three minutes to work on the item.)

Line Meanings: Turn over to the next page. At the top of this page you will see a line. List all of the things which this line reminds you of. List all of the things that it could be, all of the things that it looks like. Again, don't worry about spelling or handwriting and number your responses. Do you have any questions? Ready, begin.

(The subject was then allowed three minutes to work on the item.)

Similarities: Turn over to the next page. At the top of this page you will see the words WATCH AND TYPEWRITER,(MILK AND MEAT). You are to list all of the ways in which WATCH AND TYPEWRITER are alike. List all of the ways that you can think of in which WATCH AND TYPEWRITER are similar. Don't worry about spelling and handwriting and number your responses. Any questions? Ready, begin.

(The subject was then allowed three minutes to work on the item.)

Pattern Meanings: Turn over to the next page. At the top you will see a pattern. You are to list all of the things that this pattern reminds you of. List all of the things that the pattern could be, all of the things that it looks like. Again, don't worry about spelling or handwriting and number your responses. Any questions? Ready, begin.

(The subject was then allowed three minutes to work of the item.)

VERBAL IDEATIONAL FLUENCY STIMULUS ITEMS

I. Alternate Uses

Pretest--------------CORK

Posttest-------------CHAIR

II. Similarities

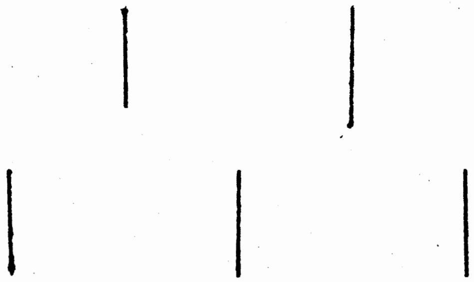
Pretest--------------WATCH AND TYPEWRITER

Posttest-------------MILK AND MEAT

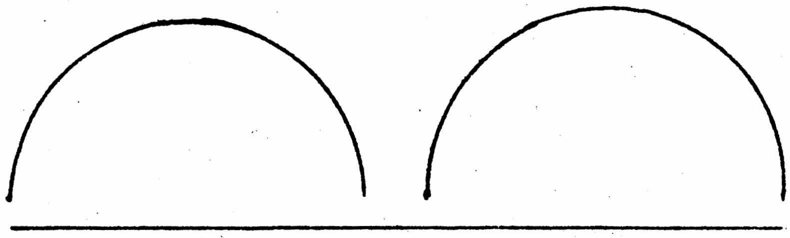
SPATIAL IDEATIONAL FLUENCY STIMULUS ITEMS

III. Pattern Meanings

Pretest

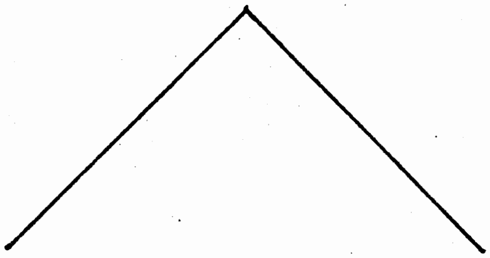


Posttest

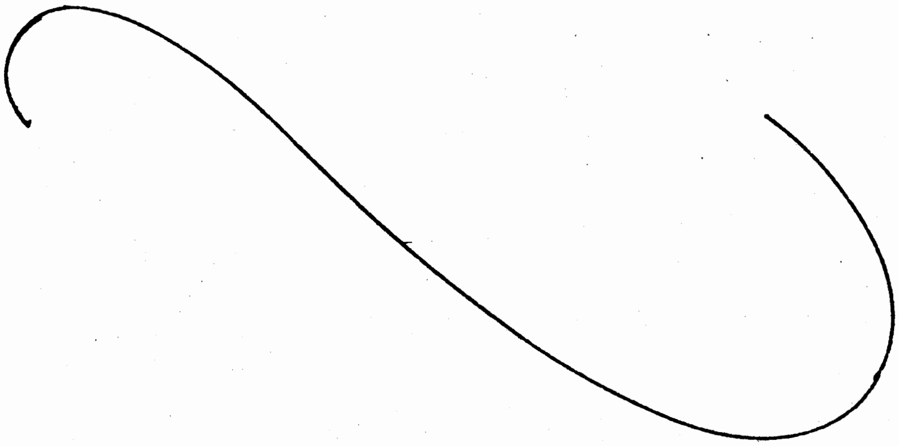


IV. Line Meanings

Pretest



Posttest



INSTRUCTIONS FOR THE REMOTE ASSOCIATES TEST

(Presented orally and in writing)

In this section you are presented with three words and asked to find a fourth word which is related to all three. Write this word in the space to the right.

For example, what word do you think is related to these three?

cookies sixteen heart _______________

The answer in this case is "sweet". Cookies are sweet; sweet is part of the phrase "sweet sixteen"; and part of the word "sweetheart".

Here is another example:

poke go molasses _______________

You should have written "slow" in the space provided. "Slow poke", "go slow", and "slow as molasses". As you can see, the fourth word may be related to the other three for a variety of reasons.

Try these next two:

A. surprise line birthday _______________

B. base snow dance _______________

The answers are at the bottom of the page.

(Assistance was provided as necessary)

Now turn to the next page and try the groups of words. Many of these items are not easy and you will have to think about them for a while. If you have trouble with some groups of three, go on to the next and come back to them later. Give only one answer to each question. You will have 20 minutes. Some of the words may be new to you so if you are uncertain how it is pronounced, simply point to it and the examiner will be happy to say it aloud. Do you have any questions? Turn to the next page and begin.

The answers are: A. party; B. ball.

PRETEST----REMOTE ASSOCIATES TEST

	Items			Answers
1.	ranger	fire	green	(forest)
2.	Sleeping	Beast	Black	(Beauty)
3.	friend	bell	scout	(boy)
4.	paper	boy	report	(news)
5.	plane	hot	borne	(air)
6.	double	blind	steady	(date)
7.	ribbon	coward	rose	(yellow)
8.	ship	outer	parking	(space)
9.	pump	patch	bike	(tire)
10.	account	large	battery	(charge)
11.	head	rotten	shell	(egg)
12.	throat	rate	cards	(cut)
13.	pin	style	dresser	(hair)
14.	arrow	laced	narrow	(straight)
15.	walk	wax	show	(floor)
16.	wall	garden	youth	(flower)
17.	hair	cooking	drill	(oil)
18.	train	pony	sorrow	(express)
19.	fence	office	out	(post)
20.	finger	prove	return	(guilty)

POSTTEST----REMOTE ASSOCIATES TEST

	Items			Answers
1.	tin	garbage	jail	(can)
2.	snow	sheet	wash	(white)
3.	moon	Monday	true	(blue)
4.	bells	mouse	steeple	(church)
5.	Northwest	secret	way	(passage)
6.	short	shop	sign	(stop)
7.	nosed	letter	cardinal	(red)
8.	blonde	gas	resources	(natural)
9.	modern	fine	craft	(art)
10.	stand	chance	supper	(last)
11.	goof	light	rocker	(off)
12.	tooth	bitter	heart	(sweet)
13.	pint	hat	economy	(size)
14.	extra	something	event	(special)
15.	swords	road	word	(cross)
16.	rules	party	chance	(game)
17.	bug	finger	killer	(lady)
18.	corner	run	ring	(around)
19.	mark	hard	lunch	(time)
20.	fly	scotch	knife	(butter)

APPENDIX C

ANALYSES OF COVARIANCE OF THE TRAINING SESSIONS FREQUENCY AND AMPLITUDE BASELINES

TABLE III

GROUP (G) X SESSIONS (S) ANALYSIS OF COVARIANCE OF THE LEFT HEMISPHERE FREQUENCY BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	1.0383	1	1.0383	0.4624	
1-st Covariate	48.8559	1	48.8559	21.7580*	0.63347
Error	29.1904	13	2.2454		
S	30.1174	7	4.3025	4.2990*	
SG	8.1796	7	1.1685	1.1675	
Error	98.0778	98	1.0007		
Linear Component	115.4200	1	115.4200	115.3300*	
Pooled Regression Coefficients					
1-st Covariate	0.63347				

$^{*}p < .001$

TABLE IV

GROUP (G) X SESSIONS (S) ANALYSIS OF COVARIANCE OF THE RIGHT HEMISPHERE FREQUENCY BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	0.1140	1	0.1140	0.0765	
1-st Covariate	32.0614	1	32.0614	21.5287*	0.40266
Error	19.3601	13	1.4892		
S	6.6171	7	0.9453	1.2830	
SG	4.0546	7	0.5792	0.7861	
Error	72.2029	98	0.7367		
Pooled Regression Coefficients					
1-st Covariate	0.40266				

$^{*}p < .001$

TABLE V

GROUP (G) X SESSIONS (S) ANALYSIS OF COVARIANCE OF THE LEFT HEMISPHERE AMPLITUDE BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	689.5820	1	689.5820	0.6734	
1-st Covariate	10730.3242	1	10730.3242	10.4790*	0.52142
Error	13311.7929	13	1023.9838		
S	1591.2578	7	227.3225	0.8118	
SG	1372.3515	7	196.0502	0.7001	
Error	27441.3515	98	280.0136		
Pooled Regression Coefficients					
1-st Covariate	0.52142				

*$p < .006$

TABLE VI

GROUP (G) X SESSIONS (S) ANALYSIS OF COVARIANCE OF THE RIGHT HEMISPHERE AMPLITUDE BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	124.8945	1	124.8945	0.3721	
1-st Covariate	28273.7421	1	28273.7421	84.2472*	1.13668
Error	4362.8554	13	335.6042		
S	418.9726	7	59.8532	0.6618	
SG	604.9179	7	86.4168	0.9555	
Error	8862.4140	98	90.4327		
Pooled Regression Coefficients					
1-st Covariate	1.13668				

*$p < .001$

APPENDIX D

ANALYSES OF COVARIANCE OF THE POSTTEST SESSIONS FREQUENCY AND AMPLITUDE BASELINES

TABLE VII

GROUP (G) ANALYSIS OF COVARIANCE OF THE LEFT HEMISPHERE POSTTEST FREQUENCY BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	0.1440	2	0.0720	0.1242	
1-st Covariate	17.8445	1	17.8445	30.7854*	1.00710
Error	11.5928	20	0.5796		
Pooled Regression Coefficients					
1-st Covariate	1.00710				

*p < .001

TABLE VIII

GROUP (G) ANALYSIS OF COVARIANCE OF THE RIGHT HEMISPHERE POSTTEST FREQUENCY BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	0.7701	2	0.3850	0.3258	
1-st Covariate	11.4307	1	11.4307	9.6740*	0.66386
Error	23.6316	20	1.1815		
Pooled Regression Coefficients					
1-st Covariate	0.66386				

*p < .006

TABLE IX

GROUP (G) ANALYSIS OF COVARIANCE OF THE LEFT HEMISPHERE POSTTEST AMPLITUDE BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	787.6535	2	393.8266	3.0216*	
1-st Covariate	307.1599	1	307.1599	2.3566	0.23820
Error	2606.7128	20	130.3356		
Pooled Regression Coefficients					
1-st Covariate	0.23820				

*$p < .071$

Planned Comparison of Biofeedback Groups on Adjusted Posttest Left Hemisphere Amplitude Means

RULD Group	RDLD Group
51.43	37.73

t-test Value for Pair Wise Comparison

RULD vs. RDLD	2.376	$p < .025$	20 df

TABLE X

GROUP (G) ANALYSIS OF COVARIANCE OF THE RIGHT HEMISPHERE POSTTEST AMPLITUDE BASELINES WITH THE PRETEST BASELINE AS THE COVARIATE

Source	Sum of Squares	df	Mean Square	F	Beta Est.
G	76.7546	2	38.3773	0.3783	
1-st Covariate	2060.1835	1	2060.1835	20.3117*	0.80677
Error	2028.5625	20	101.4281		
Pooled Regression Coefficients					
1-st Covariate	0.80677				

$^{*}\underline{p} < .001$

APPENDIX E

ANALYSES OF VARIANCE OF EEG POWER IN-TASK

TABLE XI

ANALYSIS OF VARIANCE OF THE DIVERGENT TASKS: GROUPS (G) X SUBJECTS (S) X TASK (T) X HEMISPHERE (H)

Source	Sum of Squares	df	Mean Square	F
G	1686235.00	2	843117.50	1.4243
T	93804.63	4	23451.16	0.3790
H	154432.30	1	154432.30	1.2686
S(G)	0.1243E 08	21	591961.10	
GT	631066.40	8	78883.25	1.2748
GH	294940.80	2	147470.40	1.2114
TH	118102.20	4	29525.55	1.5146
ST(G)	5197749.00	84	61877.98	
SH(G)	2556407.00	21	121733.60	
GTH	168693.70	8	21086.71	1.0817
STH(G)	1637535.00	84	19494.46	

TABLE XII

ANALYSIS OF VARIANCE OF THE CONVERGENT TASKS: GROUPS (G) X SUBJECTS (S) X TASK (T) X HEMISPHERE (H)

Source	Sum of Squares	df	Mean Square	F
G	1002062.00	2	501031.00	3.3245*
T	1755812.00	2	877906.00	31.5751**
H	92720.25	1	92720.25	2.4151
S(G)	3164914.00	21	150710.20	
GT	45615.00	4	11403.75	0.4102
GH	36257.75	2	18128.88	0.4722
TH	29049.75	2	14524.88	1.4676
ST(G)	1167755.00	42	27803.69	
SH(G)	806243.30	21	38392.54	
GTH	98287.25	4	24571.81	2.4827*
STH(G)	415680.50	42	9897.15	

*p < .07

**p < .01

Planned Comparison of Biofeedback Groups on EEG Power During Convergent Tasks

RULD Group	RDLD Group
9.797	7.759

t-test Value for Pair Wise Comparison

RULD vs. RDLD	2.5714	p < .01	21 df

TABLE XIII

ANALYSIS OF VARIANCE OF THE DIVERGENT AND CONVERGENT TASKS: GROUPS (G) X SUBJECTS (S) X TASK (T) X HEMISPHERE (H)

Source	Sum of Squares	df	Mean Square	F
G	496473.80	2	248236.90	1.5012
T	234531.50	1	234531.50	5.4830**
H	77463.81	1	77463.81	3.0707*
S(G)	3472599.00	21	165361.80	
GT	278682.60	2	139341.30	3.2576*
GH	66385.88	2	33192.94	1.3158
TH	231.1875	1	231.1875	0.0162
ST(G)	898257.40	21	42774.16	
SH(G)	529757.10	21	25226.53	
GTH	16836.31	2	8418.156	0.5883
STH(G)	300507.10	21	14309.86	

*$p < .07$

**$p < .05$

APPENDIX F

ANALYSES OF VARIANCE OF THE DIVERGENT AND CONVERGENT TASKS USING CHANGE SCORES AS THE DEPENDENT VARIABLE

TABLE XIV

ANALYSIS OF VARIANCE OF THE IDEATIONAL FLUENCY: GROUPS (G) X SUBJECTS (S) X ITEMS (I)

Source	Sum of Squares	df	Mean Square	F
G	5.6874	2	2.8437	0.3969
I	12.1145	3	4.0381	0.8605
S(G)	150.4682	21	7.1651	
GI	9.4791	6	1.5798	0.3367
SI(G)	295.6392	63	4.6926	

TABLE XV

ANALYSIS OF VARIANCE OF THE REMOTE ASSOCIATES TEST: GROUPS (G) X SUBJECTS (S)

Source	Sum of Squares	df	Mean Square	F
G	9.7500	2	4.8750	0.8769
S(G)	116.7498	21	5.5595	

TABLE XVI

ANALYSIS OF VARIANCE OF THE MINNESOTA PAPER FORM BOARD TEST: GROUPS (G) X SUBJECTS (S)

Source	Sum of Squares	df	Mean Square	F
G	1.000	2	.5000	0.0091
S(G)	1156.621	21	55.0771	

TABLE XVII

ANALYSIS OF VARIANCE OF THE DURRELL SILENT READING PARAGRAPHS: GROUP (G) X SUBJECTS (S) X TASK (T)

Source	Sum of Squares	df	Mean Square	F
G	.7624E 01	2	.3812E 01	0.0204
T	.6020E 01	1	.6020E 01	0.0554
S(G)	33.3117	21	1.5862	
GT	.3679	2	.1839	0.1692
ST(G)	22.8365	21	1.0874	

TABLE XVIII

ANALYSIS OF VARIANCE OF THE WIDE RANGE ACHIEVEMENT TEST: GROUP (G) X SUBJECTS (S) X TASK (T)

Source	Sum of Squares	df	Mean Square	F
G	18.3749	2	9.1874	2.4442
T	.2083E 01	1	.2083E 01	0.0033
S(G)	78.9373	21	3.7589	
GT	20.0416	2	10.0208	1.5890
ST(G)	132.4370	21	6.3065	

Planned Comparisons of Treatment Groups on WRAT Arithmetic Score Change

RULD Group	RDLD Group	CONT Group
1.875	0.875	-1.000

t-test Values for Pair Wise Comparisons

RULD vs. CONT	3.24	$p < .01$	21 df
RDLD vs. CONT	2.11	$p < .05$	21 df

t-test for Dependent Sample Values

RULD	3.23	$p < .02$	7 df
RDLD	.94	n.s.	7 df
CONT	-1.02	n.s.	7 df

APPENDIX G

ANALYSES OF VARIANCE OF THE DIVERGENT AND CONVERGENT TASKS USING PRE-POSTTEST SCORES AS THE DEPENDENT VARIABLE

TABLE XIX

ANALYSIS OF VARIANCE OF THE IDEATIONAL FLUENCY: GROUP (G) X SUBJECTS (S) X PRE-POST (P) X ITEMS (I)

Source	Sum of Squares	df	Mean Square	F
G	1.7812	2	0.8906	0.0536
P	3.7968	1	3.7968	1.0598
I	162.7656	3	54.2552	21.2784*
S(G)	348.9211	21	16.6152	
GP	2.8437	2	1.4218	0.3969
GI	5.7186	6	0.9531	0.3738
PI	6.0572	3	2.0190	0.8607
SP(G)	75.2324	21	3.5824	
SI(G)	160.6363	63	2.5497	
GPI	4.7394	6	.7899	0.3367
SPI(G)	147.7959	63	2.3459	

$^{*}p < .01$

TABLE XX

ANALYSIS OF VARIANCE OF THE REMOTE ASSOCIATES TEST: GROUP (G) X SUBJECTS (S) X PRE-POST (P)

Source	Sum of Squares	df	Mean Square	F
G	5.3750	2	2.6875	0.4788
P	36.7500	1	36.7500	13.2207*
S(G)	117.8748	21	5.6130	
GP	4.8749	2	2.4374	0.8769
SP(G)	58.3745	21	2.7797	

$^{*}p < .01$

TABLE XXI

ANALYSIS OF VARIANCE OF THE MINNESOTA PAPER FORM BOARD TEST: GROUP (G) X SUBJECTS (S) X PRE-POST (P)

Source	Sum of Squares	df	Mean Square	F
G	16.1666	2	8.0833	0.0637
P	1.6875	1	1.6875	0.0613
S(G)	2666.2820	21	126.9658	
GP	0.5000	2	0.2500	0.0091
SP(G)	578.3308	21	27.5395	

TABLE XXII

ANALYSIS OF VARIANCE OF THE DURRELL SILENT READING PARAGRAPHS: GROUP (G) X SUBJECTS (S) X PRE-POST (P) X TASK (T)

Source	Sum of Squares	df	Mean Square	F
G	0.3727	2	0.1863	0.0313
P	0.3384	1	0.3384	0.4267
T	26.1462	1	26.1462	35.3346*
S(G)	125.0763	21	5.9560	
GP	0.3812E 01	2	0.1906E 01	0.0240
GT	0.2679E 01	2	0.1339E 01	0.0181
PT	0.3002E 01	1	0.3002E 01	0.0552
SP(G)	16.6559	21	0.7931	
ST(G)	15.5392	21	0.7399	
GPT	0.1838	2	0.9193E 01	0.1691
SPT(G)	11.4184	21	0.5437	

*$p < .01$

TABLE XXIII

ANALYSIS OF VARIANCE OF THE WIDE RANGE ACHIEVEMENT TEST: GROUP (G) X SUBJECTS (S) X PRE-POST (P) X TASK (T)

Source	Sum of Squares	df	Mean Square	F
G	0.2708	2	0.1354	0.0026
P	7.5937	1	7.5937	4.0405*
T	4.5937	1	4.5937	0.0983
S(G)	1107.965	21	52.7602	
GP	9.1874	2	4.5937	2.4442
GT	55.1874	2	27.5937	0.5904
PT	0.1041E 01	1	0.1041E 01	0.0033
SP(G)	39.4678	21	1.8794	
ST(G)	981.4668	21	46.7365	
GPT	10.0207	2	5.0103	1.5893
SPT(G)	66.2055	21	3.1526	

*$p < .07$

APPENDIX H

SPEARMAN RANK ORDER CORRELATIONAL MATRICES OF BASELINE AROUSAL CHANGE AND PRE-POSTTEST SCORE IMPROVEMENT

TABLE XXIV

SPEARMAN RANK ORDER CORRELATION COEFFICIENTS OF THE TRAINING SESSION BASELINE CHANGE X PRE-POSTTEST SCORE IMPROVEMENT FOR THE RULD GROUP

	Baseline Hemisphere and EEG Parameter[a]						
Tests	left frequency	right frequency	left amplitude	right amplitude	left hemisphere	right hemisphere	total
Ideational Fluency							
Alternate Uses	.17	-.04	.31	-.32	.36	-.24	-.04
Lines	-.53	.12	.57	-.18	-.04	-.04	-.08
Similarities	.05	.19	.00	.13	.06	.18	.25
Patterns	-.20	.07	-.17	-.05	-.35	-.10	-.21
Verbal IF	-.03	-.05	.04	.07	.05	-.04	.02
Spatial IF	-.38	-.11	.11	-.17	-.30	-.31	-.38
Remote Associates Test	-.14	.66*	.93**	-.38	.57	.31	.57
Durrell Silent Reading Paragraphs							
Rate	-.10	-.26	-.16	.84**	-.20	.35	.09
Comprehension	.10	.45	.02	.07	.10	.46	.36
Minnesota Paper Form Board	.13	-.04	-.40	.30	-.30	.10	.02
Wide Range Achievement Test							
Spelling	.51	-.15	.07	-.07	.55	-.02	.17
Arithmetic	-.25	-.35	-.50	.90**	-.60	.24	-.17

*$p < .05$

**$p < .01$

[a] Ranks calculated by amount of increased arousal in the right hemisphere and decreased arousal in the left hemisphere.

TABLE XXV

SPEARMAN RANK ORDER CORRELATION COEFFICIENTS OF THE TRAINING SESSION BASELINE CHANGE X PRE-POSTTEST SCORE IMPROVEMENT FOR THE RDLD GROUP

	Baseline Hemisphere and EEG Parameter[a]						
Tests	left frequency	right frequency	left amplitude	right amplitude	left hemisphere	right hemisphere	total
Ideational Fluency							
Alternate Uses	-.38	-.33	.07	-.64*	-.36	-.53	-.55
Lines	.51	.54	-.01	.43	.36	.51	.79*
Similarities	.08	-.15	-.01	-.17	-.02	-.15	.05
Patterns	-.32	-.02	.39	-.06	-.02	-.11	-.08
Verbal IF	-.21	-.29	-.05	-.53	-.32	-.43	-.31
Spatial IF	-.18	.19	.39	-.02	.09	.04	.17
Remote Associates Test	.01	-.11	-.01	-.64*	.06	-.46	-.42
Durrell Silent Reading Paragraphs							
Rate	.38	.04	.38	.30	.46	.13	.29
Comprehension	.08	.03	.80*	.06	.70*	-.02	.35
Minnesota Paper Form Board	-.79*	-.12	.00	.10	-.74*	.07	-.40
Wide Range Achievement Test							
Spelling	.40	.55	-.30	.48	.05	.60	.49
Arithmetic	-.37	-.61	.29	-.09	-.10	-.40	-.54

$^{*}p < .05$

[a] Ranks calculated by amount of decreased arousal in each hemisphere.

TABLE XXVI

SPEARMAN RANK ORDER CORRELATION COEFFICIENTS OF THE TRAINING SESSION BASELINE CHANGE X PRE-POSTTEST SCORE IMPROVEMENT FOR THE RULD AND RDLD GROUPS

	Baseline Hemisphere and EEG Parameter[a]						
Tests	left frequency	right frequency	left amplitude	right amplitude	left hemisphere	right hemisphere	total
Ideational Fluency							
Alternate Uses	-.05	.03	-.24	.43*	-.15	.22	.05
Lines	.09	-.59*	.30	.12	.32	-.30	-.14
Similarities	.13	-.02	.16	.13	.23	.10	.18
Patterns	.08	-.05	.06	.21	.08	.11	.05
Verbal IF	.06	-.04	-.12	.38	.03	.19	.14
Spatial If	.15	-.08	-.20	.03	-.04	-.05	-.16
Remote Associates Test	.15	.41	-.45*	.23	-.21	.39	.21
Durrell Silent Reading Paragraphs							
Rate	.05	.03	.14	.54*	.05	.34	.29
Comprehension	.06	.43*	-.12	-.02	-.20	.24	.13
Minnesota Paper Form Board	.39	-.02	.28	.04	.49*	-.01	.32
Wide Range Achievement Test							
Spelling	-.35	-.37	.03	-.32	-.13	-.45*	-.53*
Arithmetic	.36	.12	.16	.48*	.34	.36	.53*

*$p < .05$

[a] Ranks calculated by amount of increased arousal (increased frequency, decreased amplitude).

VITA

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Doctor of Philosophy

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