

# Voluntary Control of Patterns of EEG Parietal Asymmetry: Cognitive Concomitants

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## ABSTRACT

This experiment addressed two questions: 1) is training for EEG parietal asymmetry using pattern biofeedback accompanied by predictable cognitive concomitants? and 2) are the cognitive concomitants of training for simultaneous bilateral activation of the hemispheres a simple additive combination of the two asymmetry patterns, or do they represent a unique cognitive gestalt not readily predictable from the two asymmetry training conditions? Bilateral parietal EEG was recorded from 20 right handed subjects and filtered for 8–13 Hz activity. The four possible EEG patterns were quantified on line. All subjects received 12 min of EEG symmetry training ( $L\alpha^{off}R\alpha^{off}$ -Integration) and 12 min each of EEG asymmetry training ( $L\alpha^{off}R\alpha_{on}$  and  $L\alpha_{on}R\alpha^{off}$ -Differentiation). Significant regulation of all three patterns was obtained. Analysis of post feedback questionnaires revealed that  $L\alpha^{off}R\alpha_{on}$  regulation was associated with significantly more verbal cognitions, while the  $L\alpha_{on}R\alpha^{off}$  pattern was associated with more visual cognitions. EEG symmetry regulation ( $L\alpha^{off}R\alpha^{off}$ ) produced a third pattern of cognitions different from both asymmetry conditions. The data suggest that feedback stabilized cortical patterning is associated with predictable cognitive concomitants and that pattern biofeedback procedures can be used to uncover the relationships between brain processes and subjective experience.

**DESCRIPTORS:** Cerebral lateralization, EEG pattern biofeedback, Subjective state, Cognition, Self-regulation.

Recent research and theorizing has suggested that cognition and subjective experience are emergent properties of the patterning of underlying neural activity (e.g. Sperry, 1969; Schwartz, 1975). This thesis has emerged from research strategies where the cognitive state of the subject has been both the independent and dependent variable. For example, in the area of cerebral asymmetry, Galin and Ornstein (1972) and others (e.g. Davidson, Schwartz, Pugash, & Bromfield, in press; Doyle, Ornstein, & Galin, 1974; McKee, Humphrey, & McAdam, 1973; Robbins & McAdam, 1974; Callaway & Harris, 1974; Morgan, McDonald, & MacDonald, 1971; Morgan, MacDonald, & Hilgard, 1974; Butler & Glass, 1974; Dumas & Morgan, 1975) have demonstrated task dependent asymmetry with sub-

jects showing relative left hemisphere activation during verbal and numerical tasks and relative right hemisphere activation during spatial and musical tasks using bilateral EEG as a dependent measure. These findings have been obtained with both overt and covert response requirements. Using lateral eye movements as a dependent measure of hemispheric activation, Schwartz, Davidson, and Maer (1975) have recently observed predictable patterning of eye movement asymmetry in response to complex cognitive and affective questions. Specifically, spatial-emotional questions, a pattern hypothesized to maximally activate the right hemisphere elicited a greater number of left and a fewer number of right movements than comparable verbal non-emotional questions. The number of left and right movements elicited by the remaining two cells of the  $2 \times 2$  fell predictably in between the extreme conditions.

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Recent advances in biofeedback research have provided a new paradigm for studying the relationships between physiological patterning and subjective experience. Schwartz (1975) has recently elucidated this approach and has suggested that "self-regulation as a general strategy is useful because it enables researchers to isolate component

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parts of systems and then examine how they combine to produce unique physiological and associated subjective states [p. 323].” For example, this basic approach has been applied to the study of the subjective effects of self-regulated cardiovascular integration and differentiation (Schwartz, 1972). It was found that when naive, uninstructed subjects were given feedback and reward for the pattern of heart rate and blood pressure decreases ( $HR_{down}BP_{down}$ ) they began to spontaneously and consistently report feelings of relaxation and calmness. None of the remaining three patterns was associated with consistent reports of relaxation. Importantly, in previous research designed to train only single systems, i.e. heart rate or blood pressure, no consistent subjective concomitants were observed in minimally instructed subjects (see Schwartz, 1975). Similarly, Hassett and Schwartz (1975) found that the pattern consisting of HR slowing and occipital alpha on ( $HR_{down}Occ_{on}$ ) elicited reports of subjective relaxation more often than the remaining three conditions of the  $2 \times 2$ .

This approach to the study of the physiological substrates of affect and cognition, i.e. training subjects to self-regulate patterns of biological processes with subjective report as the main dependent measure, has yet to be systematically applied to the study of modes of cognition associated with differential pattern training of EEG symmetry and asymmetry. Most previous research employing bilateral EEG in the study of cerebral asymmetry have employed the physiological measure as the exclusive dependent variable. Two preliminary reports by Peper (1971, 1972) have been the only exceptions.

The present study was designed to explore two major questions: 1) Is training for EEG parietal asymmetry using pattern biofeedback accompanied by predictable cognitive concomitants? and 2) Are the cognitive concomitants of training for simultaneous bilateral activation of the hemispheres simply an additive combination of cognitions associated with relative left and right hemisphere activation or do they represent a unique non-additive cognitive gestalt which is not readily predictable from the two asymmetry training conditions?

#### Methods

##### Subjects

The sample was comprised of 20 students, 10 males and 10 females whose mean age was 20.5 yrs. Subjects were limited to those expressing a clear right-hand preference, and whose immediate families included no non-right handedness. All were paid volunteers and in good health.

##### Apparatus and Recording Procedure

Bilateral EEG was recorded from the left and right parietal areas ( $P_3$  and  $P_4$ ) (Jasper, 1958), referenced to the left ear lobe; the right ear lobe served as ground. EEG was recorded with

Beckman miniature electrodes and all electrode resistances were below 5000 ohms. All measures were recorded on a Grass Model 7 polygraph with each of the two EEG channels recorded through an AC preamplifier. Each EEG channel was filtered for 8–13 Hz, full wave rectified and displayed on two additional channels individually calibrated to yield a pen deflection of 3 cm for an average peak alpha burst. Level detectors were set to trigger in response to a signal at or exceeding 1 cm so that alpha activity had to be at least 33.3% of the average peak amplitude to be counted. Grason-Stadler logic modules were employed to detect instances of criterion alpha on line and to sample at .1 sec intervals to determine which of the following four conditions was present: a)  $L\alpha_{on}R\alpha_{on}$ ; b)  $L\alpha_{on}R\alpha^{off}$ ; c)  $L\alpha^{off}R\alpha_{on}$ ; d)  $L\alpha^{off}R\alpha^{off}$ .  $L\alpha_{on}R\alpha_{on}$  and  $L\alpha^{off}R\alpha^{off}$  are considered integration states, while the remaining two patterns are considered differentiation (see Schwartz, 1974). It should be recognized that use of the term integration in this context is not meant to necessarily imply synchrony of the underlying neural activity. Rather, it is used in a descriptive sense to refer to those points in time when bilateral alpha presence or absence are detected.

It should be noted that despite full wave rectification and 33% response criterion levels, this procedure tended to overestimate the percent time in the  $L\alpha^{off}R\alpha^{off}$  state, since the sampling pulse was not phase-locked to the occurrence of alpha, and epochs between peaks of the waves were at times seen as non-alpha. This procedure is therefore a conservative one, particularly with regard to its sensitivity to the two differentiation patterns.

##### Procedure

The first stage of the experiment consisted of a partial replication of an experiment by Schwartz, Davidson, Maer, and Bromfield (1974) on EEG asymmetry during whistling, singing and talking. These data will be reported elsewhere (see Davidson et al., in press).

The second phase consisted of 3 blocks of biofeedback training each consisting of a total of 12 1-min trials; 9 feedback trials with 1 rest period interspersed between every 3 trials. Each block began with a 3-min free play period during which time the subject was instructed to experiment with different strategies and try to discover what makes the tone go on and off. Each biofeedback block represented training on a different EEG pattern. Subjects were simply told that the tone represented a particular EEG pattern and that each block represented a different pattern. This entire phase was performed with eyes closed. The subjects were monitored on closed circuit video to insure compliance with this instruction.

Following each biofeedback block, subjects filled out a questionnaire designed to assess their cognitive strategy during the preceding task trials. The questionnaire asked “to what extent would you say your strategy for turning on (or turning off in the case of integration) the tone involved the following kinds of thoughts?” Subjects were required to circle a number from 1 (not at all) to 7 (nearly exclusively) which best represented their degree of involvement with each of the following six thought categories: a) verbal, b) numerical, c) visual, d) musical, e) emotional, f) thinking nothing.

The first block consisted of  $L\alpha^{off}R\alpha^{off}$  training (I). Logic modules were programmed to provide a tone each time the subject produced any pattern other than  $L\alpha^{off}R\alpha^{off}$ . Subjects were instructed to keep the tone off for as long as possible, thereby producing  $L\alpha^{off}R\alpha^{off}$ . The pitch of the tone employed for this block was alternated from subject to subject. A suppression paradigm (i.e., turn the tone off) was employed for this block

because the  $L\alpha^{off}R\alpha^{off}$  pattern typically accounted for the greatest amount of EEG activity during a 1-min block and it was reasoned that if feedback was provided for the occurrence of this pattern, the subjects would find it difficult to discriminate between a "good" vs "poor" trial due to an abundance of tones. Additionally, in order to keep the subjects interested and motivated, they were always exposed to this block first because it was believed to be easier than the subsequent asymmetry training. The EEG data confirmed this prediction and indicated that the subjects did acquire greater specificity of control over EEG symmetry versus asymmetry.

Blocks 2 and 3 consisted of the differentiation training. Order of training on each of the two differentiation patterns ( $L\alpha^{off}R\alpha_{on}$  = Differentiation 1;  $L\alpha_{on}R\alpha^{off}$  = Differentiation 2) was counter-balanced across subjects as was the pitch of the tone (low or high) representing the  $L\alpha^{off}R\alpha_{on}$  and  $L\alpha_{on}R\alpha^{off}$  states. Tones were presented each time the subject produced the criterion pattern and subjects were instructed to keep the tone on for as long as possible. During rest trials they were simply instructed to rest with their eyes closed and let their thoughts wander.

**Data Analysis**

Four scores representing each of the four EEG patterns were obtained for each task and rest trial. Each number represents a .1 sec occurrence of a particular pattern. Each of the four pattern scores obtained for each trial was converted to percent of the total number of samples for that trial. This eliminated effects of slight variations in trial length. All data analyses were performed on these transformed percent scores.

For clarity of presentation, following the presentation of resting EEG data, the effects of differentiation training on differentiation scores and cognitive activity will be discussed, followed by a consideration of the integration data. To assess the significance of training effects, analyses of variance with condition and pattern as repeated factors were performed. Two tailed *t*-tests were employed to assess the significance of individual comparisons when a significant *F* was obtained. Differences in self-reported cognition during integration and differentiation training were assessed with two-tailed *t*-tests for correlated means. Unless otherwise indicated, the rejection region is  $p > .05$  throughout.

**Results**

**Rest Data**

In order to evaluate the stability of the 1/3 average peak alpha burst criterion, an analysis was performed on resting data in the 3 training blocks. The analysis tested whether there was any consistent change over time in each of the four EEG patterns, from the first through the third resting period in each training block. If the criterion setting was stable, no significant time effects should be observed during the rest epochs. Analysis of variance with Time (rest 1, rest 2, and rest 3) and Condition (D1, D2 and I) as repeated factors was performed on each of the four EEG pattern scores. No significant main effect for Time was obtained for any EEG pattern: for  $L\alpha_{on}R\alpha_{on}$ ,  $F(2/38)=0.63$ ,  $MS_e=6.77$ ; for  $L\alpha^{off}R\alpha^{off}$ ,  $F(2/38)=0.19$ ,  $MS_e=6.91$ ; for  $L\alpha_{on}R\alpha^{off}$ ,  $F(2/38)=0.23$ ,  $MS_e=1.4$ ; for  $L\alpha^{off}R\alpha_{on}$ ,  $F(2/38)=0.54$ ,  $MS_e=3.05$ , nor was any significant Condi-

tion by Time interaction obtained. Furthermore, correlations computed across subjects (rest 1 to rest 3) were all positive and highly significant (mean  $r=.612$ ). These data suggest that the alpha level criterion remained stable over time.

**Differentiation Training: EEG Data**

The EEG data for each of the two differentiation conditions (mean of 9 trials per condition) and for the mean rest for patterns  $L\alpha_{on}R\alpha^{off}$  and  $L\alpha^{off}R\alpha_{on}$  are presented in Fig. 1. Analysis of variance revealed a Condition (D1 vs D2 vs Rest)  $\times$  Pattern ( $L\alpha^{off}R\alpha_{on}$  vs  $L\alpha_{on}R\alpha^{off}$ ) interaction ( $F(2/38)=16.74$ ,  $MS_e=45.37$ ) thus indicating reliable acquisition of control over cortical asymmetry. The main effect for pattern was also significant ( $F(1/19)=17.31$ ,  $MS_e=124.43$ ) indicating that subjects spent approximately 2% more time in the  $L\alpha^{off}R\alpha_{on}$  vs the  $L\alpha_{on}R\alpha^{off}$  pattern across experimental conditions. During D1 training subjects showed significantly less  $L\alpha_{on}R\alpha^{off}$  activity than during rest ( $t(19)=3.94$ ) and than during D2 training ( $t(19)=4.23$ ). The difference between  $L\alpha_{on}R\alpha^{off}$  activity during D2 vs Rest was not significant. The difference in  $L\alpha^{off}R\alpha_{on}$  activity between D1 and D2 was significant ( $t(19)=3.65$ ) as was the D2 vs Rest comparison on this pattern ( $t(19)=3.35$ ). The difference between D1 vs Rest on  $L\alpha^{off}R\alpha_{on}$  was not significant. Thus, relative to rest, brief training in each of the two differentiation conditions resulted in significant suppression of the untrained differentia-

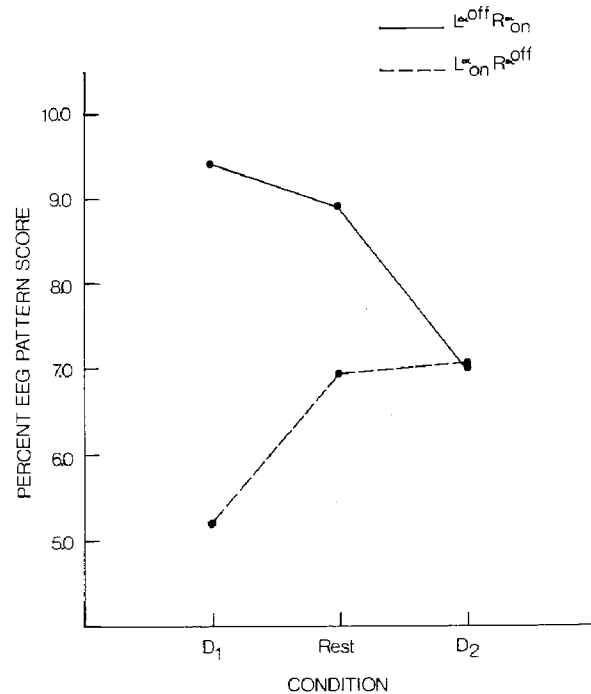


Fig. 1. Mean EEG pattern score for D1 (training on  $L\alpha^{off}R\alpha_{on}$ ), D2 (training on  $L\alpha_{on}R\alpha^{off}$ ) and Rest, for each differentiation pattern.

tion pattern; no criterion pattern w percent of the training and 75% for D2 training

Data on self-feedback training: D1 training ( $L\alpha_{on}R\alpha_{on}$ ) port significant D2 training ( $L\alpha_{on}R\alpha_{on}$ ) port significant ( $L\alpha_{on}R\alpha_{on}$ ) con The remaining significant. Th to produce two asymmetry le nitive activity documented a brains of intact & Beaumont,

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**Thought Categories**

- Verbal
- Visual
- Numerical
- Musical
- Nothing
- Emotional

\* $p < .05$ ,

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... pattern; no significant enhancement of the criterion pattern was observed relative to rest. Eighty percent of the subjects showed this effect for D1 training and 75% of the subjects showed the effect for D2 training.

**EEG Data**

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**Cognitive Concomitants**

Data on self-reported cognitive mode during feedback training are presented in Table 1. During D1 training ( $L\alpha^{off}R\alpha_{on}$ ), uninstructed subjects report significantly more verbal thought than during D2 training ( $t(19)=2.75$ ). In contrast, subjects report significantly more visual activity during D2 ( $L\alpha_{on}R\alpha^{off}$ ) compared to D1 training ( $t(19)=2.40$ ). The remaining D1-D2 comparisons were non-significant. These data reveal that training subjects to produce two opposite patterns of EEG parietal asymmetry leads to predictable shifts in cognitive activity which is consistent with the well documented asymmetry of cognitive function in the brains of intact right-handed humans (e.g. Dimond & Beaumont, 1974).

**Integration: EEG Data**

The first question which may be asked concerning the integration training is whether the abundance of the differentiation patterns ( $L\alpha_{on}R\alpha^{off}$  and  $L\alpha^{off}R\alpha_{on}$ ) remain the same or decrease relative to the two differentiation conditions. Since subjects were asked to produce the  $L\alpha^{off}R\alpha^{off}$  pattern during integration, the production of any of the three remaining patterns was possible when subjects were not in  $L\alpha^{off}R\alpha^{off}$ . An analysis of variance with Condition (D1 vs D2 vs I vs Rest) and Pattern ( $L\alpha_{on}R\alpha^{off}$  and  $L\alpha^{off}R\alpha_{on}$ ) as repeated factors revealed a highly significant main effect for condition ( $F(3/47)=18.66, MS_e=63.48$ ) indicating that during in-

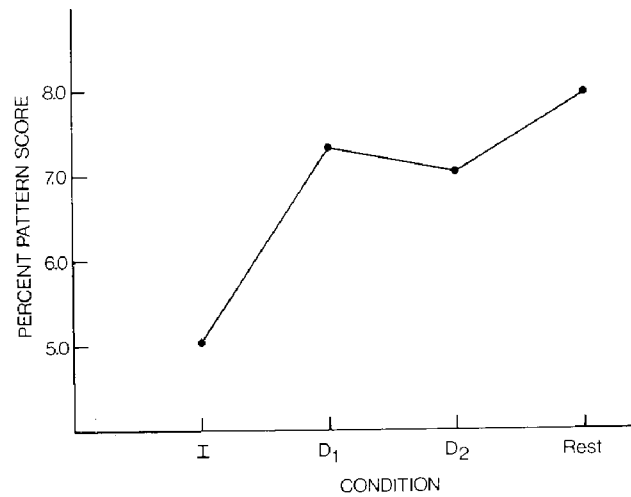


Fig. 2. Mean differentiation score (across  $L\alpha_{on}R\alpha^{off}$  and  $L\alpha^{off}R\alpha_{on}$ ) in each condition.

tegration training, subjects produced significantly less differentiated EEG (across  $L\alpha_{on}R\alpha^{off}$  and  $L\alpha^{off}R\alpha_{on}$ ) than during either of the two differentiation conditions and than during rest. These data are illustrated in Fig. 2. A significant main effect for Pattern was also obtained ( $F(1/19)=15.66, MS_e=146.06$ ), as was a Condition  $\times$  Pattern interaction ( $F(3/57)=14.02, MS_e=30.98$ ).

Separate  $t$ -tests comparing Integration to D1 and Integration to D2 revealed highly significant effects for both: for I vs D1  $t(19)=3.95$ ; for I vs D2  $t(19)=3.38$ . This indicates that the mean percent time differentiation was significantly greater during D1 and D2 relative to I. For D1 vs I the difference in percent time differentiation is 2.3% while for D2 vs I it is 2.0%.

What effect does Integration training have on Integration Patterns ( $L\alpha_{on}R\alpha_{on}$  and  $L\alpha^{off}R\alpha^{off}$ )? An analysis of variance with Condition (D1, D2, I, and Rest) and Pattern ( $L\alpha_{on}R\alpha_{on}$  and  $L\alpha^{off}R\alpha^{off}$ ) as repeated factors revealed a highly significant main effect for Condition ( $F(3/57)=18.67, MS_e=63.48$ ). These data indicate that during Integration training subjects showed significantly more mean integrated EEG activity (averaged across the two integration patterns). Separate  $t$ -tests revealed that this finding was independently significant for every comparison with Integration: for I vs D1  $t(19)=3.95$ ; for I vs D2  $t(19)=3.38$ ; and for I vs Rest  $t(19)=4.99$ . A highly significant Condition  $\times$  Pattern interaction was also found ( $F(3/57)=14.58, MS_e=319.13$ ). This interaction is illustrated in Fig. 3 and reveals that during I training ( $L\alpha^{off}R\alpha^{off}$ ), there was an increase in  $L\alpha^{off}R\alpha^{off}$  activity relative to the two differentiation conditions and relative to rest. Separate  $t$ -tests indicated that each comparison with Integration (on  $L\alpha^{off}R\alpha^{off}$ ) was highly significant: for I vs D1  $t(19)=5.06$  (90% of the subjects showed this ef-

TABLE 1

Mean self-reported cognitive mode on a 1-7 scale for each of six thought categories during each biofeedback treatment. The right side presents difference scores for each of the three comparisons

Thought Categories	Mean Cognitive Modes			Difference Scores		
	D1	D2	I	D1-D2	D1-I	D2-I
Verbal	3.92	2.40	2.35	1.52*	1.57*	0.05
Visual	3.55	4.65	5.10	-1.10*	-1.55*	-0.45
Numerical	2.80	1.85	2.55	0.95	0.25	-0.70
Musical	2.85	2.25	2.05	0.60	0.80	0.20
Nothing	2.45	2.40	4.35	0.05	-1.90*	-1.95*
Emotional	4.00	4.00	2.60	0.00	1.40*	1.40

\* $p < .05$ , 2-tailed  $t$  test for correlated means.

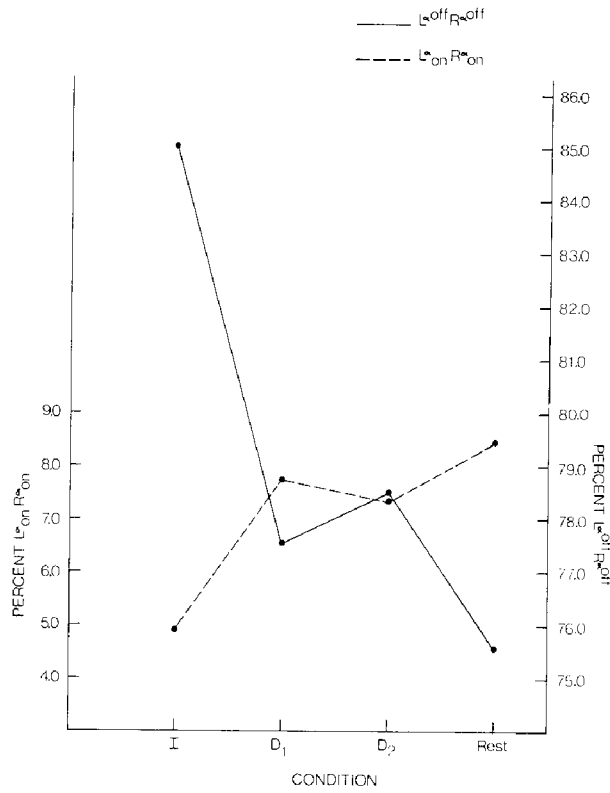


Fig. 3. Mean pattern score for D1, D2, I, and Rest, for each integration pattern.  $L\alpha_{on}R\alpha_{on}$  is plotted on the left axis;  $L\alpha_{off}R\alpha_{off}$  is plotted on the right axis.

fect); for I vs D2  $t(19)=4.36$  (90% of the subjects showed this effect); for I vs Rest  $t(19)=6.37$  (90% of the subjects showed this effect). Importantly, on the integration pattern which was not rewarded ( $L\alpha_{on}R\alpha_{on}$ ) a decrease during I relative to the remaining three conditions was observed. Separate  $t$ -tests indicated that on the  $L\alpha_{on}R\alpha_{on}$  pattern, I vs Rest was significant ( $t(19)=2.43$ ) and I vs D1 was non-significant ( $t(19)=1.94$ ). The I vs D2 comparison was also not significant.

These findings reveal the reliable acquisition of specificity of integration control. It should be recalled that the EEG was sampled every .1 sec so that if the presence of criterion level alpha activity rapidly alternated between the hemispheres during I training, it might not be reflected in increases in the integration pattern but rather could be reflected in percent time differentiation. Interestingly, during  $L\alpha_{off}R\alpha_{off}$  training the subjects, on the average, increased the target pattern as well as decreased the opposite integration pattern. This is in contrast to the differentiation training results where the subjects tended to primarily decrease the non rewarded pattern. Thus these data suggest that the subjects demonstrated greater specificity of control over EEG symmetry versus asymmetry.

Finally, a highly significant main effect for pattern was obtained ( $F(1/19)=1427.02$ ,  $MS_e=207,471.13$ ). The magnitude of this differ-

ence can be attributed to the recording procedure which, as previously indicated, tended to accentuate the  $L\alpha_{off}R\alpha_{off}$  pattern.

### Integration: Cognitive Concomitants

Data on self-reported cognition during Integration training are included in Table 1. It can be seen that during I ( $L\alpha_{off}R\alpha_{off}$ ) training, subjects report themselves to be thinking nothing significantly more than during either differentiation block. At first glance, this finding appears somewhat paradoxical since it might be predicted that a greater increase in overall cognition during training for bilateral EEG activation would occur. However, an examination of the subjects' responses to an open ended question concerning strategies employed for making the tone go off revealed that 65% reported intense concentration on a single or a small number of images. Thus, although experiencing intense concentration, these subjects reported a moderate degree of thinking nothing since the usual ongoing stream of cognition (cf. Singer, 1975) was temporarily attenuated.

During I, subjects reported less emotional thoughts than during either D1 or D2, but this difference was not significant. They also reported fewer verbal and more visual cognitions during I than during D1.

These data on self-reported cognition during Integration training suggest that the production of the  $L\alpha_{off}R\alpha_{off}$  pattern is not simply accompanied by an increase in both verbal and visual thoughts as would be predicted from a simple additive model. Rather, the cognitive data reveal that the subjective concomitants of bilateral EEG activation are different from either asymmetry pattern alone, or from their combination.

### Discussion

These data indicate that when uninstructed subjects are given feedback for asymmetrical patterns of EEG alpha activity, they can rapidly acquire significant control over these patterns with relatively brief training (a total of 12 min each pattern). The corresponding findings on self-reported cognitions during differentiation training are striking, considering the brevity of the training and the fact that the subjects were completely uninformed with respect to knowledge of which EEG parameters were being trained. That predictable correspondence between self-reported cognition and EEG patterning was obtained in such a short time might partially be a function of certain aspects of the procedure used. It should be noted that integration training was always provided first and was followed by the presentation of the cognitive category questionnaire. It is possible that the range of strategies invoked by subjects in the subsequent asymmetry

conditions was in questionnaire. I categories which between D1 and D2 are the two cog consistently been a hemisphere acti dependent mea Doyle et al., 1975. The present data concerned with metry and cog

Interestingly training, the su unrewarded dif but they did not of the rewarded hancement may than was prov Interestingly, t served during b than those occ talking and sim parisons for the to 250%). It wa more systemati sponding, with

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<sup>1</sup>It should also be quantification and two differentiation differentiation and given an initial as of the criterion lev cal decrease in alp ing system as  $L\alpha_{off}R\alpha_{off}$  alpha rarely fell b was relatively ins hancement of the be a function of discussions of the patterns of physio

conditions was narrowed by clues obtained from the questionnaire. Nevertheless, the only two thought categories which significantly discriminated between D1 and D2 training—i.e., verbal and visual—are the two cognitive modes which have most consistently been associated with relative left and right hemisphere activation respectively using EEG as a dependent measure (e.g. Galin & Ornstein, 1972; Doyle et al., 1974; Robbins & McAdam, 1974). The present data support and extend previous studies concerned with relationships between EEG asymmetry and cognitive mode.

Interestingly, during EEG asymmetry pattern training, the subjects succeeded in suppressing the unrewarded differentiation pattern relative to rest, but they did not evidence significant enhancement of the rewarded pattern relative to rest. Such enhancement may require a longer training period than was provided in the present experiment.<sup>1</sup> Interestingly, the magnitude of the changes observed during biofeedback appear somewhat larger than those occurring during the overt whistling, talking and singing trials in part 1 (percent comparisons for the four EEG scores range from 110% to 250%). It would be valuable in future research to more systematically compare overt and covert responding, with and without biofeedback.

Concerning integration training, when subjects were given feedback for EEG symmetry in the form of bilateral activation, they also readily acquired significant control with a degree of specificity not observed during differentiation training. During integration, subjects, on the average, both increased the abundance of the target pattern as well as decreased the percent time of the other integration pattern. This is consistent with the notion that there may be a greater constraint for cortical differentiation in the normal intact human brain than integration. However, this finding needs to be interpreted with caution since integration training was always provided first and subjects may conceivably have been fatigued during the subsequent differentiation training.

Importantly, the cognitive findings from the inte-

<sup>1</sup>It should also be noted that the procedure employed for EEG quantification and feedback was conservative with respect to the two differentiation patterns; it tended to minimize percent time differentiation and maximize percent integration. For example, given an initial asymmetry of  $L\alpha_{on}R\alpha_{off}$  with  $P_4$  alpha at 110% of the criterion level and  $P_3$  alpha at 90% of the level, a symmetrical decrease in alpha level by 20% would be seen by the recording system as  $L\alpha_{off}R\alpha_{off}$ . Although, based on visual inspection, alpha rarely fell below the  $\frac{1}{2}$  criterion, the procedure employed was relatively insensitive to asymmetry. Thus, the lack of enhancement of the rewarded differentiation pattern may partially be a function of the EEG quantification method (for further discussions of the utilization of binary procedures for tracking patterns of physiological processes on line, see Schwartz, 1974).

gration condition suggest that the production of such a state is not simply the sum of the two differentiation patterns. Such a simple additive model would predict increases in both visual and verbal cognition during integration. The present data suggest, however, that the production of  $L\alpha_{off}R\alpha_{off}$  is associated with a different pattern of cognition. It should be recognized that the production of bilateral parietal activation may be accomplished in a myriad of ways, few of which naturally involve the *simultaneous* generation of verbal and visual thought. Rather, the simultaneous activation of both hemispheres may typically involve the generation of *complementary* behavior and cognition. For example, a number of subjects in the present experiment reported visualizing an image and holding the image in awareness. Such a strategy is similar to some meditation techniques which require the generation and maintenance of an image in consciousness. Banquet (1973) has reported that such a technique, at certain points during meditation, leads to bilateral activation (i.e., increments in beta activity in both hemispheres) in the EEG.

A number of limitations of the present experiment should be pointed out. First, the questionnaire employed as the dependent measure to assess cognitive variables was a relatively simple one. Moreover, the questionnaire was specifically designed to uncover possible differences in cognition during asymmetry training as suggested from the prior literature. Future research with a similar paradigm might benefit from a more extended questionnaire with additional items reflecting more complex cognitions which might naturally be associated with bilateral activation. Second, it is not entirely clear from the present study whether the significant differences in cognition observed between D1, D2 and I are in fact a function of the relatively small EEG shifts from one self-regulation condition to another or are more a function of learning to discriminate which subjective thoughts and feelings are associated with different EEG patterns. Correlations in the present experiment between cognition and EEG patterning were generally positive, but only one reached significance (the largest  $r = .444$ ,  $p < .05$  between verbal cognitions and EEG differentiation change scores during  $L\alpha_{off}R\alpha_{on}$  training). Failure to obtain high correlations between physiological changes and subjective experience, despite significant modifications in both the physiological responses and subjective report with biofeedback training, has been reported in other self-regulation experiments (e.g. Sirota, Schwartz, & Shapiro, 1974), and is deserving of further research. More sensitive, multi-trial, within subject designs assessing cognitive processes after each trial are required to get at this question.

Finally, it should be noted that EEG was recorded

from only two sites ( $P_3$  and  $P_4$ ) in the present experiment. It is possible that with additional cortical locations (e.g. Davidson, Schwartz, & Rothman, Note 1; Schwartz, Davidson, & Margolin, Note 2) as well as the inclusion of autonomic variables which are presumably more sensitive to subcortical processes (e.g. Galin, 1974), and/or specific skeletal responses (e.g. Schwartz, Fair, Salt, Mandel, & Klerman, 1976), biofeedback for selected patterns of central and peripheral processes could lead to stronger associations with predictable patterns of cognitive processes.

Altogether the present findings support the gen-

eral thesis that a pattern biofeedback approach to self-regulation of neural patterns can be a useful research tool in the study of the biological basis of cognition and subjective experience. The data are consistent with recent theorizing suggesting that cognition and subjective experience are non-additive properties of neural patterning and illustrate the application of pattern self-regulation procedures to the study of the neural mechanisms of cognition by elucidating how different physiological systems combine to produce unique subjective gestalts (Schwartz, 1975).

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