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Effect of Problem Solving on Right and Left Hemisphere 40 Hertz EEG Activity

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ABSTRACT

EEG activity within the alpha, beta II and 40 Hz bands was monitored during periods of problem solving and non-problem solving. Concomitant 40 Hz EMG activity was also monitored to show a dissociation between it and 40 Hz EEG activity. Twenty-four right-handed subjects were used. Results indicate that during problem solving there is a reduction in activity within the alpha and beta II bands relative to non-problem solving periods. Within the 40 Hz EEG band there was increased activity over the hemisphere assumed to be maximally engaged in the problem solving task. Activity within the 40 Hz EMG band showed bilateral increases during problem solving. It was also found that 40 Hz EMG activity made little, if any, contribution to 40 Hz EEG activity.

DESCRIPTORS: EEG and problem solving, 40 Hz EEG.

A number of studies have appeared recently concerning a high frequency, low amplitude electroencephalographic (EEG) signal centered at 40 hertz (Hz). This narrow band (36–44 Hz), high frequency EEG activity has been shown to be a covariate of focused arousal (Sheer, 1970, 1976, Note 1), a component of problem solving or cognitive activity.

Several studies (Sheer, 1970, 1975, 1976; Spydell, Ford, & Sheer, 1979) have shown that 40 Hz activity in man increases during periods of problem solving compared to similar non-problem solving periods. Sheer (1976) has presented data from a group of normal children showing that EEG activity within the 40 Hz band increased significantly during a variety of problem solving tasks. However, when the same tasks were presented to a group of age and IQ matched learning disabled children, no activity increases were found within the 40 Hz band. In addition, the learning disabled children displayed performance deficits relative to the normal children.

A later study (Spydell et al., 1979) has shown that the increases in 40 Hz activity which occur during problem solving are not diffusely distributed over the brain, but are greatest over the brain area maximally engaged in the problem solving task. This study found that during the solving of verbal problems 40 Hz activity shows a relatively greater increase over the left hemisphere than over the right hemisphere. Conversely, during the solving of spatial problems there is a relatively greater increase in 40 Hz activity over the right hemisphere. These findings are in close agreement with what would be predicted from the many studies of hemispheric lateralization of the alpha rhythm (Doyle, Ornstein, & Galin, 1974; Galin & Ornstein, 1972).

The studies cited above show the consistent increases in 40 Hz EEG activity found during problem solving but still leave open the question of the relationship between 40 Hz activity and the more traditionally monitored, lower frequency EEG activities. Sheer (1976) has shown that while 40 Hz activity increases during problem solving, bordering activity bands centered at 30 and 50 Hz do not change from non-problem solving levels. This finding demonstrates that increases in 40 Hz activity are restricted to the 40 Hz band and are not influenced by activity in neighboring bands. This finding also indicates that beta II activity may not be related to 40 Hz EEG activity.

This possibility has been supported by two studies of 40 Hz EEG biofeedback training in humans (Bird, Newton, Sheer, & Ford, 1978a,

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1978b). These investigators found no correlation between 40 Hz EEG activity and beta II activity during successful biofeedback training to increase 40 Hz EEG activity (Bird et al., 1978b). In another study (Bird et al., 1978a) these same investigators demonstrated that little or no change occurred in the beta II band while subjects successfully learned to either increase or decrease 40 Hz EEG activity. While it may be argued that the process of biofeedback training to increase or suppress 40 Hz EEG activity and problem solving are qualitatively different and that the results of each should not be used to support the other, the biofeedback results presented above strongly indicate that the organization of the neural substrates involved in generating 40 Hz and beta II activity may not be common to each other.

A recurring argument leveled against the 40 Hz EEG research to date is that the 40 Hz activity being recorded may be an artifact of electromyographic (EMG) activity rather than of neurologic origin. Special coincidence detection units, which have been previously described (Bird et al., 1978a, 1978b; Sheer, 1976; Spydell et al., 1979), have been used to control for this potential source of confounding. In addition, recent studies have presented evidence that is inconsistent with an EMG interpretation of 40 Hz EEG activity.

All of the research previously cited (Bird et al., 1978a, 1978b; Sheer, 1970, 1975, 1976; Spydell et al., 1979) have failed to find a correlation between 40 Hz EEG and 40 Hz EMG activity during any of the tasks or conditions used. In support of the failure to find a relationship between 40 Hz EEG and 40 Hz EMG activity is a large group of data which argues against an EMG source for 40 Hz EEG activity on logical grounds. Sheer (1976) has shown that increases in 40 Hz activity during problem solving are not accompanied by increases in surrounding activity bands centered at 30 and 50 Hz. If the signals being recorded in the 40 Hz band were of EMG origin, approximately equal increases would be expected across these three frequency bands due to the wide frequency range occupied by EMG activity. This activity has been variously estimated to occupy bandwidths ranging from 10–70 Hz (Friedman, cited in Goldstein, 1972) to 2–10,000 Hz (Buchthal, Pinelli, & Rosenfalck, 1954). While the precise frequency range of EMG activity may still be in question, it can easily be seen to occupy a much broader range of frequencies than the narrow 36–44 Hz frequency range of 40 Hz EEG activity.

Additional evidence from this same study (Sheer, 1976) further argues against an EMG interpretation of 40 Hz EEG activity. When the data from the age and IQ matched group of learning disabled children was compared to the data from the normal children, it was found that activity within the 30 and 50 Hz bands did not differ across the two groups. However, as previously presented, the learning disabled group did not show increased 40 Hz activity during problem solving and also displayed performance deficits on the cognitive tasks. It is doubtful that a discrete band of EMG activity would exhibit this type of relationship to cognitive activity.

Further evidence against the EMG origins of 40 Hz EEG activity comes from another study that was reviewed earlier (Spydell et al., 1979). This study found that while clear, predictable patterns of hemispheric lateralization could be seen for 40 Hz EEG activity during three of the four tasks used, no evidence for similar patterns of lateralization of 40 Hz EMG activity could be found. Using all possible pairings of the four tasks used, only one pairing showed lateralization of 40 Hz EMG activity, and these two tasks did not differ in hemispheric distribution of 40 Hz EEG activity. If EMG activity were responsible for the task appropriate asymmetries seen in the 40 Hz EEG activity, some more consistent relationship between EMG and EEG activity within the same frequency band would be expected.

While the findings presented above may fall short of conclusively demonstrating that 40 Hz EEG activity is not an artifact of 40 Hz EMG activity, they do make that argument more difficult to support on logical grounds. The present study attempts to provide additional data bearing on the question of 40 Hz EEG and EMG activities, and in addition examined the relationships between alpha, beta II and 40 Hz EEG activity during periods of problem solving and non-problem solving.

Method

Subjects

Twenty-four subjects, aged 18–30 yrs, were used. All subjects had been previously administered a test of cerebral dominance that included tests of hand, eye and foot dominance, and were judged to be right side dominant. Due to a shortage of EEG filters alpha and beta II activity were recorded from the left side of the head in half the subjects and from the right side of the head in the other half. Forty hertz EEG activity was recorded bilaterally in all subjects as was EMG activity. EMG activity for all subjects was judged to be low, with potential EMG confounding occupying no more than 10% of the total EEG sample time for each condition.

Procedures

Grass silver disc electrodes filled with conductive paste were used. Active EEG electrodes were placed approximately in the middle of the O_1-P_3-T_5 triangle of the International Ten-Twenty System (Jasper, 1958) on the left side of the head and in a corresponding position on the right side of the head. These electrode sites were designated X_1 and X_2 respectively and were chosen because they lie approximately over the parietal-occipital-temporal junction, an area thought to be involved in higher order integrative processes. A reference EEG electrode was located at C_z of the International Ten-Twenty System.

Since the 40 Hz EEG band is overlaid by low frequency muscle activity, EMG was recorded as a control. EMG electrodes were placed over the splenius muscles and over the temporal muscles on both sides of the head. EMG activity was recorded bilaterally. A ground electrode was placed on the forehead at the hairline. All recordings were bipolar and resistances for all electrodes were below 5K ohms.

Five Grass EEG amplifiers (Model 7P511) were used to amplify the EEG and EMG signals. Three of the amplifiers received EEG activity. One amplifier was adjusted for alpha activity, with a high-pass filter setting of 3 Hz, while the other two amplifiers used a high-pass filter setting of 10 Hz and amplified beta II and 40 Hz activity. Two amplifiers received EMG activity and also used a high-pass filter setting of 10 Hz. Low-pass filters were set at 90 Hz for all five amplifiers and their sensitivity was adjusted to maximum (×100,000). All amplifiers also had their 60 Hz filters switched off. Chart speed was adjusted to 100mm/sec so that high frequency, low amplitude activity in the record could be visually inspected.

Amplified EEG and EMG signals went to a number of bandpass filters. All filters were high-Q, narrow band (3dB per octave), twin-T analog filters (White Instrument Co., Austin, Texas). The EEG signal from the amplifier adjusted for alpha activity was directed to an alpha bandpass filter (8–13 Hz, Model 3465). The EEG signals from the other two amplifiers were routed to separate bandpass filters for beta II (21–31 Hz, Model 3465) activity, 40 Hz (36–44 Hz, Model 3385) activity, and 70 Hz (62–78 Hz, Model 3385) activity. Amplified EMG signals were routed to separate bandpass filters for 40 Hz (36–44 Hz, Model 3385) and 70 Hz (62–78 Hz, Model 3385) activity. The output from these bandpass filters was then rectified, integrated, and subjected to response detection criteria. Criteria for detecting an EEG or EMG response were as follows: alpha = 300 msec of 15–29 μV activity; beta II = 120 msec of 10–15 μV activity; 40 Hz = 75 msec of 5–10 μV activity; 70 Hz = 75 msec of 5–10 μV activity. Activity that met these criteria produced a count on an associated digital counter.

To provide counts from the EEG leads for 40 Hz activity that was not contaminated with 40 Hz EMG activity, a coincidence detection unit (Sheer, 1976) was used. This unit received the integrated and rectified outputs from both the 40 Hz EEG and 40 Hz EMG filters as well as from the 70 Hz EEG and EMG filters. Circuits within the coincidence detection unit function in the following manner: when 40 Hz activity is encountered in an EMG channel any 40 Hz activity in the ipsilateral EEG channel within 200 msec following the EMG event is inhibited. Similarly, when 70 Hz activity is present in either an EEG or EMG channel, any 40 Hz activity in the EEG channel during the following 200 msec is also inhibited. This control was based on the finding that 40 Hz EMG activity detected at scalp electrodes was accompanied by polyphasic activity from approximately 30 to 100 Hz, while 40 Hz EEG was not (Sheer, 1975). A block diagram of the signal conditioning and data acquisition circuit is shown in Figure 1.

The counts obtained by the circuit described above represented bursts of three consecutive cycles of activity within the pass-band of the respective filter. Counts for alpha, beta II, total 40 Hz activity from the EEG electrodes and for 40 Hz activity from the EEG electrodes that were free of coincident 40 Hz EMG activity, as well as 40 Hz EMG activity were obtained. The total 40 Hz activity from the EEG electrodes was labeled "40 Hz Total," while 40 Hz activity free of coincident 40 Hz EMG activity was labeled "40 Hz EEG."

Subjects were seated in a reclining chair located in a sound attenuated, electronically shielded room adjacent to the room housing the recording and control equipment. A 5-min non-problem solving period was recorded during which subjects were instructed to sit quietly and relax with their eyes open and to avoid thinking about anything. Following this, two tests were presented visually, using a slide projector and rear projection screen. The order of presentation for the tests was counterbalanced across all subjects. The tests used were a 6-item verbal analogies test and a 20-item geometric figure rotation test. These tests have been described previously (Spydell et al., 1979).

Data collection was discontinued during the answer interval following each test item to avoid muscle artifacts. Following administration of the tests another 5-min non-problem solving period was recorded.

Data Analysis

The number of counts obtained from all activity bands during both non-problem solving periods were combined and a rate per minute for each activity band was calculated for each subject. Likewise, the counts obtained for

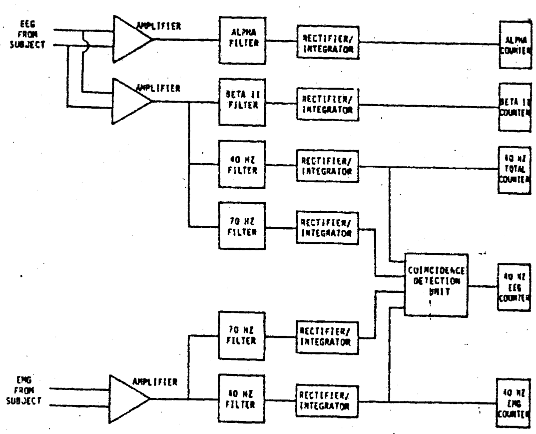

Figure 1. Block diagram of signal conditioning and data acquisition circuit.

TABLE 1

Median changes in rate scores

	Median Rate Score Changes									
	Alpha		Beta II		40 Hz Total		40 Hz EEG		40 Hz EMG	
Problems	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Verbal	−36.7*	−52.4*	−20.1*	−20.2*	1.0*	0.1	1.2*	0.1	8.4*	10.6*
Rotation	−36.7*	−37.6*	−15.3*	−15.3*	0.7	1.0*	0.4	0.9*	13.9*	8.9*

*$p<.05$.

each subject during each of the problem solving tasks were converted to a rate per minute. The problem solving rates were then contrasted with the non-problem solving rates to determine changes in activity within each band as a consequence of cognitive activity. The comparisons were made separately for the right and left sides of the head.

In order to further examine the relationships between activity in the 40 Hz total, 40 Hz EEG and 40 Hz EMG bands, a measure of the relative change in activity between non-problem solving and problem solving was derived. This measure was a ratio score determined by the formula: problem solving rate minus non-problem solving rate divided by problem solving rate plus non-problem solving rate. Negative ratios indicated decreased activity during problem solving. These ratio scores allowed each subject to serve as his own control, thus greatly reducing inter-subject variability. The ratio scores were then used to contrast changes in activity over the right and left sides of the head and to calculate correlation coefficients between the various 40 Hz activity bands within each problem solving and recording site condition. A two-tailed rejection region of $p<.05$ was used throughout data analysis.

Results

Multiple Wilcoxon tests were used to determine any changes in activity as a consequence of problem solving. Within the alpha band activity decreased over both the right and left sides of the head during both problem solving tasks (verbal analogies: left, T = 12, $n^1 = 12$, $p<.05$; right, T = 1, $n^1 = 12$, $p<.01$; figure rotation: left, T = 8, $n^1 = 12$, $p<.02$; right, T = 3, $n^1 = 12$, $p<.01$). Similar results were obtained within the beta II band with activity showing a decrease over both sides of the head during problem solving (verbal analogies: left, T = 12, $n^1 = 12$, $p<.05$; right, T = 6, $n^1 = 12$, $p<.01$; figure rotation: left, T = 12, $n^1 = 12$, $p<.05$; right, T = 14, $n^1 = 12$, $p<.05$).

Within the 40 Hz EEG band activity increased over the left side of the head during the verbal analogies (T = 29, $n^1 = 22$, $p<.01$). An increase was also found over the right side of the head during the figure rotation task (T = 33, $n^1 = 23$, $p<.01$). A similar pattern was found for 40 Hz Total activity (verbal analogies: left, T = 73, $n^1 = 24$, $p<.05$; figure rotation: right, T = 41, $n^1 = 24$, $p<.01$). Forty hertz EMG activity increased on both the right and the left sides during both tasks (verbal analogies: left, T = 48, $n^1 = 24$, $p<.01$; right, T = 23, $n^1 = 24$, $p<.01$; figure rotation: left, T = 12, $n^1 = 24$, $p<.01$; right, T = 4.5, $n^1 = 24$, $p<.01$). The median activity rate changes for these various bands are presented above in Table 1.

The median ratio scores for 40 Hz activity from both the EEG and EMG recording electrodes are presented in Table 2. A Wilcoxon test was used to contrast changes in 40 Hz EEG activity over the left and right sides of the brain as a consequence of problem solving. This analysis revealed a greater increase over the left hemisphere during the verbal problems (T = 18, $n^1 = 24$, $p<.05$) and a greater increase over the right hemisphere during the figure rotation problems (T = 72, $n^1 = 24$, $p<.05$). No left or right side specific changes were found for 40 Hz EMG measures.

Finally, a series of Spearman rank-order correlations were performed between the various 40 Hz activities. The results of these analyses are presented in Table 3. No significant correlations were noted between 40 Hz EMG activity and either 40 Hz Total or 40 Hz EEG activity.

Discussion

The results of the current study within the EEG domain are not totally unexpected. A number of previous studies (Glass, 1964; Kreitman & Shaw,

TABLE 2

Median ratio scores between various 40 Hz activities

	Median Ratio Scores					
	40 Hz Total		40 Hz EEG		40 Hz EMG	
Problems	Left	Right	Left	Right	Left	Right
Verbal	.15	.07	.22*	.09	.34	.29
Rotation	.13	.42	.22	.37*	.33	.38

*$p<.05$.

TABLE 3

Spearman rank-order correlations between various 40 Hz activity measures

	Correlations							
	Verbal Left		Verbal Right		Rotations Left		Rotations Right	
40 Hz Measures	40 Total	40 EEG	40 Total	40 EEG	40 Total	40 EEG	40 Total	40 EEG
40 Hz EEG	.74*		.68*		.94*		.78*	
40 Hz EMG	.27	.28	.39	.05	.27	.35	.16	.25

*$p<.05$.

1965) have shown that alpha activity displays a marked reduction during mental activity. Likewise, the increases in 40 Hz EEG activity as a consequence of problem solving are consistent with the data reviewed earlier in this paper. A somewhat surprising result was to find a decrease in beta II activity during problem solving. At the very least this finding suggests that a reduction in amplitude of activity within the beta II band occurs during problem solving. The answer to what is happening within the beta II band during problem solving will require a more detailed examination of that frequency domain.

The EEG results as a whole do support the earlier suggestion by Sheer (1976) that 40 Hz EEG activity is differentiable from beta II activity. Not only does 40 Hz EEG activity increase during problem solving while beta II activity decreases, but 40 Hz EEG increases are selective to the hemisphere assumed to be maximally engaged in the task presented. While 40 Hz EEG activity did show some mean increases in rate over the minimally involved hemispheres (the right during verbal analogies and the left during the figure rotation task), these increases tended to be more variable and less reliable across subjects.

Of more interest are the results of analyses of 40 Hz activity from EEG and EMG recording sites. While 40 Hz EMG activity increased symmetrically during both problem solving tasks, increased 40 Hz EEG activity was limited to the left side of the head during the verbal task and to the right side of the head during the figure rotation task. It is difficult to see how these results could be obtained if 40 Hz EEG activity were a consequence of 40 Hz EMG activity.

The results of the present study also suggest that if 40 Hz EMG activity is making any contribution to 40 Hz activity recorded at the EEG electrode, the contribution is quite small. Even though 40 Hz EMG shows a marked increase during problem solving, as can be seen in Table 1, the differences between 40 Hz Total and 40 Hz EEG activity remain fairly constant. This can also be seen in the correlations presented in Table 3. While 40 Hz Total and 40 Hz EEG activity are highly correlated for both tasks on either side of the head, both 40 Hz Total and 40 Hz EEG show no correlation with 40 Hz EMG activity. This can occur only if 40 Hz EMG activity is making little or no contribution to 40 Hz activity being recorded at the EEG electrode.

These results, together with the findings reviewed earlier, would appear to support the idea that 40 Hz EEG activity is not an artifact of 40 Hz EMG activity. The current study also supports the idea that 40 Hz EEG activity is differentiable from beta II activity. These two findings suggest that cortical 40 Hz EEG activity in humans is a distinct and unique neural activity.

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