stantial deterioration of monitoring efficiency. Bidirectional experimental manipulation of theta activity in the occipital-parietal EEG seems to affect monitoring performance in a profound and systematic manner. The theta rhythm may be associated with presumed arousal processes that determine monitoring efficiency under monotonous conditions. This is the first demonstration, to our knowledge, of a lawful relationship between operantly regulated cortical phenomena and performance in man.

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Coupling between Cortical Potentials from Different Areas

Abstract. *At any instant, the electroencephalogram can be classified as to (i) polarity and (ii) direction of change in polarity. This classification provides a way to measure coupling between cortical areas. The technique is simple, yet of wide potential utility for studying functional relationships between cortical areas. The results of applying this technique suggest how the potentials giving rise to the electroencephalogram may play a role in information processing in the central nervous system.*

Suppose that the electroencephalogram (EEG) does reflect signals that are used by the brain, and is not just a sign of metabolic activity. The wavelike qualities of the EEG are not likely to be effective carriers of information. A 10-hertz wave needs at least 100 msec to be established, and that is too slow a rate to account for complex information processing in the brain. Indeed, wavelike EEG activity generally indicates information processing more by its absence than by its presence (for instance, alpha blocking).

Sensitivity of neural activity to intrinsic fields such as those generated by the EEG is suggested by Kaczmarek and Adey (*1*). We were thus led to examine the more or less instantaneous aspects of the EEG for evidence of relationships between EEG and information processing. When two areas of the brain are in active functional communication, then some sensible relationship should exist between the EEG's from these two areas. The two EEG's can, at any instant, be classified on the basis of polarity and direction of change of potential (that is, slope), and the results of such a classification can be used to measure coupling. By experimentally changing functional communication between the two areas, we can determine whether our measure of coupling changes as functional coupling changes. This last procedure serves to test the hypothesis about the relationship of the EEG to information processing in the brain.

To measure coupling between two EEG channels, the two channels were sampled every 4 msec. Each of the two samples was classified as to whether its polarity was positive (+) or negative (−), and as to whether its voltage was greater (↑) or smaller (↓) than the preceding sample from the same channel. Each sample could thus be classified in one of four categories (+↑, +↓, −↑, and −↓), and the contingencies (between the two channels) were tallied into a 4 by 4 table for a fixed number of samples. The degree of coupling between the two channels could be computed from the contingency table in a variety of ways (chi square, correlations, and so forth). We measured coupling by using the coefficient of information transmission or uncertainty reduction (*2*) because of its computational simplicity.

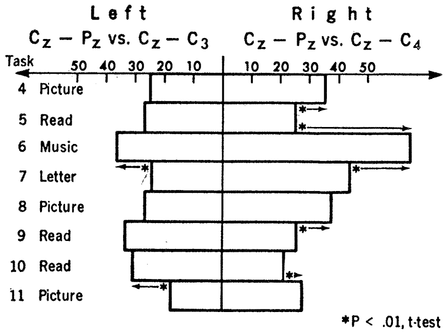

Fig. 1. Coefficients of information transmission for subject R.P.

Functional communications between visual area and each of the left and right hemispheres were manipulated by assigning verbal (left hemisphere) and spatial (right hemisphere) tasks to the subjects (*3*). We recorded EEG's from three derivations, one at the posterior midline near the visual cortex (P_z) and one each at the middle of the right (C_4) and left (C_3) hemispheres, all with the vertex (C_z) as reference. The choices of C_z as reference and of P_z as near visual cortex were made to avoid contamination from muscle artifact as much as possible. The nine subjects were right-handed and familiar with current concepts of the differentiation of hemispheric function. During the early part of each sitting, we tried pilot procedures (such as reversing Necker cubes and sorting photographs), but during the latter part of the sitting, all subjects were given four standard tasks to perform on command. These tasks were (i) read—silently reading interesting text as rapidly as possible; (ii) picture—examining interesting details of a picture; (iii) music—listening to Mozart with eyes closed; and (iv) letter—composing a letter mentally with eyes closed. Read and picture were each done twice; letter and music, only once.

The read task was designed to call for verbal propositional processing of visual data and hence to enhance occipital-left hemisphere coupling, whereas the picture task was intended to be "visual-appositional" (*3*) so as to enhance occipital-right hemisphere coupling. Little instruction was required for read, but for picture the subject was urged to notice details and to relate them to himself in an appositional way. After the first picture trial, the subject was interrogated as to how well he avoided verbal associations. He

Table 1. The effects of tasks on coupling to left and to right. Values shown are left-right differences in coefficients of information transmission: the coefficient for C_z-P_z versus C_z-C_3 minus the coefficient for C_z-P_z versus C_z-C_4. Read and picture values are averages of results from two tasks each. Only single letter and music tasks were used; $\bar{x}$, mean.

Subject	Eyes open			Eyes closed	
	Read	Picture	Read minus picture	Letter	Music
J.H.	115.0	94.8	20.2	111.0	81.2
G.R.	64.1	48.6	15.5	− 21.4	− 7.5
S.S.	38.2	24.4	13.8	30.3	10.4
C.Y.	13.5	0.2	13.3	− 9.8	− 11.4
E.C.	− 1.9	− 13.5	11.6	25.4	34.4
R.P.	8.9	− 9.2	18.1	− 18.0	− 27.4
R.H.	10.6	− 3.4	14.0	4.8	20.1
R.J.	34.9	43.2	− 8.3	41.5	29.0
G.P.	44.0	30.9	13.1	− 14.9	1.9
			$\bar{x}$ = 12.4 t = 4.5		

was told whether his degree of coupling in the picture task shifted from that for read on as many as two trials; this was an attempt to achieve the proper performance before data were collected for statistical purposes.

Coefficients of information transmission were computed for 4-second epochs from the 1000 samplings of potentials at 4-msec intervals accumulated into each contingency table. The EEG sampling was continuous during a given task, and computation for an epoch was done while the data of the succeeding epoch were being collected.

Two pairs of channels were treated simultaneously. These were C_z-P_z versus C_z-C_3, for coupling between occiput and left hemisphere; and C_z-P_z versus C_z-C_4, for coupling between occiput and right hemisphere. After each task was maintained for 160 seconds (computation of 40 4-second epochs), the means and standard deviations of the two coefficients of information transmission were printed.

We predicted that in the eyes-open condition, the read task should enhance left coupling and picture should enhance right coupling. Table 1 summarizes data on the last six standard tasks (two read, two picture, one letter, and one music) recorded on nine consecutive subjects. Each value is the coefficient of left information transmission minus the coefficient of right information transmission. In 15 of 18 read-picture pairs (two for each subject), the left-right difference was greater for read. If mean left-right differences for each subject are considered, the value of t for read-picture differences is 4.5 ($P < .01$). This is as predicted.

Figure 1 shows subject R.P.'s records in more detail. A read task and two novel tasks involving picture sorting were performed first, and then the standard tasks were done serially as shown. After the first picture and the following read task, the subject was told that she was performing as we wished. Then the six tasks for statistical evaluation in Table 1 were done. In each shift between picture and read, the right-side coupling was greater for picture than for read (t-test, $P < .01$). Left coupling differed significantly between the last read and picture, and the difference was in the opposite (predicted) direction from that for right coupling. Music caused significantly more coupling both for left and right than did any other task.

The data support the hypothesis that this EEG measure reflects information transmission between cortical areas, but alternative explanations must be considered. One possibility is that the reading task could reduce the left-right difference of EEG power (*4*). This could allow a signal appearing both occipitally and centrally to contribute relatively more to the left than to the right. This in turn would increase the left-right coupling difference. By using tasks with eyes closed, we attempted to see if an increase in common EEG activity (increased alpha activity with eyes closed) would increase the left-right coupling difference during a left-sided task (letter) compared to either a right-sided, eyes-closed task (music) or a left-sided, eyes-open task (read). In both comparisons, the results failed to support this alternative; the left-right coupling difference for letter was smaller than that for read in six of nine cases and smaller than that for music in four of nine cases.

A second possibility concerns extracerebral potentials. It is hard to imagine how the electroculogram could contribute a potential common to the occiput and to the central lead of one side without making a similar contribution to the opposite side. However, tension of shoulder and neck muscles on the left produces an increase in left-right coupling differences. There was no muscle activity visible in the EEG records made during testing of the subjects, nor is there reason to suppose that reading would produce a consistent increase in left-side muscle activity. Yet, more extensive experience with a larger variety of tasks is needed to thoroughly test these possibilities. Meanwhile, our original hypothesis seems at least tenable.

"Appositional" processing of visual data tends to increase coupling between the occiput and the right hemisphere, and "propositional" processing tends to increase coupling to the left. Changes in EEG coupling that accompany changes in cognitive processing, disclosed by this method of decoding the EEG, support the idea that the EEG is related to electrical events involved in information processing in the central nervous system. Sensitivity of neural tissue to electrical gradients on the order of those that give rise to the EEG is not outlandish when one considers that the lateral line organs of *Gymnarchus* (African knife fish) are sensitive to gradients of about 0.15 μv/cm (*5*).

This new EEG measure is sensitive to the change in functional coupling, and is computationally so simple as to be well within the capability of the smallest computer. It is easily generalized to N dimensions (that is, multiple and partial interrelations) (*6*) and so should be useful in examining less obvious interrelations among cortical areas than the ones reported here. Variations in amplifier frequency response, sampling rate, and epoch (window) size, and the use of higher-order differences all need to be explored in a more thorough parametric fashion, and in a wider variety of sittings. Initial data suggest that the use of epochs longer than 4 seconds reduces both the measurement of information and the significance of task-induced differences. Conventional cross-correlations were taken on 4-second samples, and the absolute (unsigned) Z' transforms were averaged. The results were highly correlated with our mean coefficients of information, but computation was more cumbersome. For the present our approach seems suitable as an alternate to more conventional time series measures (such as cross-spectra and coherences) for studying relations between EEG and brain information processing.

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$$H = -\sum_{i=1}^{N} P_i \log_2 P_i$$

For a given EEG channel, $N = 4$, and P_i is estimated from the relative frequency of EEG samples classified into each of the four categories. If uncertainty in channels x and y are H_x and H_y, and that in the contingency matrix is $H_{x,y}$, the coefficient of information transmission is

$$100\ (H_x + H_y - H_{x,y}) / (\text{minimum } H_x, H_y)$$

In the present example, H_x and H_y were always quite close to 2, so the reader can easily convert to approximate information transmission in bits.
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On the "Square" Model of Maya Territorial Organization

Marcus has offered some models of Maya hierarchial place arrangement and claims that locational analysis, which she "borrowed from cultural geography," confirms her epigraphic analysis (*1*, p. 911).

Of particular interest to the cultural geographer are the maps supposed to illustrate this confirmation. Her figure 4 represents a regional capital (Palenque). Around the regional capital, she says, "developed the familiar hexagonal lattices of secondary centers predicted by the Central-Place Theory " (*1*, p. 911). To me it looks more like a square.

In her figure 5, "Calakmul, one of the four regional capitals . . . surrounded by six secondary centers with almost equidistant spacing" (*1*, p. 913), it is of interest that the angles shown are more easily explained as multiples of 9° than as derivatives of 60°. In her figure 6, "Hexagonal lattices in the vicinity of Tikal . . ." (*1*, p. 914), I notice that the same is true. (Uaxactun-Palmar = 117°, Palmar–San Clemente = 108°, San Clemente–Dos Aguadas = 54°, Dos Aguadas–Uaxactum = 81°, El Gallo–Nakum = 54°.)

In her choice of apical places, Marcus suggests, but does not specify, epigraphic reasons. Of the six places, two ("?" and "?") cannot have convincing epigraphic evidence of relationship to Tikal, and of the remainder, only one—Nakum—would seem to qualify. However, a marriage is not usually regarded as evidence of subservience, but of equality.

I have offered some hypotheses regarding Maya territorial organization (*2*). I might summarize them in the following sentence: The Maya landscape does not represent the blind working-out of economic factors, but is a single, coherent, and highly planned arrangement of places, relationships, and areas.

It seems that attempts to analyze landscapes into predetermined polygonal patterns are stymied when the people subjected to this scheme have a strong, nonhexagonal geometric plan of their own. This, I believe, is the case with the lowland Maya.

If we cannot "tile" the Maya "plane" with hexagons, we can at least "till the plains" of Yucatec research and look at sites which have names other than "?". Perhaps square research has more to offer than hexagonal after all.

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Marcus's demonstration of the territorial organization of the Lowland Classic Maya (*1*) shows the striking regularity of distribution of major ceremonial centers in the areas around Tikal and Calakmul, based on the survey data of Bullard (*2*) and Ruppert and Denison (*3*) and continuing the rather late application of locational theory in the field of Maya studies which began in 1972 (*4*). The trends and regularities noted in her article are, however, present over a far larger area of the Southern Maya Lowlands (or Central Area) in the Late Classic than she gives evidence for. There is evidence to support not only her contention, "that there was, between A.D. 600 and 900, an overall organization of the entire Maya lowlands" (*1*, p. 911), but also mine, "that the overall distribution of major centres is in fact a function of the whole network, with local factors determining only the actual siting—in other words, that strategic location dominates tactical siting rather than otherwise" (*5*).

I have discussed (*5*) the overall distribution of Late Classic major ceremonial centers in the Central Area, showing by the use of locational analysis (principally distance from the nearest neighbor) that fairly uniform lattices of different sizes existed all over the rain-forest zone, with the distances between sites and the sizes of their "regions of control" decreasing steadily toward a "core" in northeast Petén, Guatemala, where Bullard's survey was carried out. This model depended on coeval and coequal functioning of major centers in the Late Classic, but the possibility of a hierarchy of such centers was canvassed and regretfully excluded because of the unreliability of most of the available data on site size, "since the nature of the inequality and its permanence are factors at present only hinted at in the few recent large-scale site plans and recent epigraphic work" (*5*).

I have noted Bullard's "restatement in practical and archaeological terms of Christaller's theory of central places" and have suggested that "the recent work of Hodder [*6*] on the 'ceremonial centers' of Roman Britain, the walled towns, shows that the model can and should be applied to the Classic Maya situation, although the level of data availability and reliability is much lower."

This casually flung gauntlet Marcus has now taken up. The notion of Copán,