Physiological Studies of Consciousness

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Psychologist Robert Ornstein's work has won awards from more than a dozen organizations, including the American Psychological Association and UNESCO. His research on the specialization of the brain advanced our understanding of how we think. He has published 26 books on the human mind and brain and their relationship to thought, health and individual and social consciousness, which have sold over six million copies and been translated into a dozen other languages. Dr. Ornstein has taught at the University of California Medical Center and Stanford, and lectured at 200 universities. He is the president of the Institute for the Study of Human Knowledge (ISHK), which brings important discoveries on human nature to the public.

NOTE

This monograph is based on a lecture given to the Institute for Cultural Research by Dr Ornstein in London on 5 October 1973. It is an account of work done by him and David Galin, M.D. at the Langley Porter Neuropsychiatric Institute, University of California Medical Center, San Francisco.

Physiological Studies of Consciousness

For the past several years we and our colleagues at the Langley Porter Neuropsychiatric Institute in San Francisco have been studying the biological mechanisms underlying two modes of consciousness. We have primarily studied brain electrical activity (EEG) and eye movements. In this paper we will review some of the history of the lateralization of brain function and describe two recent experiments.

The asymmetrical localization of cognitive function in the human brain has long been studied. Language was ascribed to the left hemisphere by Dax in 1836 (Brain, 1956). Since then clinical work with brain damaged patients has continued to differentiate the cognitive functions of the hemispheres (Semmes et al., 1955; Milner, 1965a; Luria, 1966; Corkin, 1965). For example, right temporal lobectomy produces a severe impairment on visual and tactile mazes. In contrast left temporal lobectomy of equal extent produces little deficit on these tasks. but impairs verbal memory (Milner, 1965a, Corkin, 1965). In general, clinical work has found verbal and arithmetical functions (analytic, linear) depend on the left hemisphere while spatial relationships (holistic, gestalt) are the special province of the right hemisphere. Sperry, Gazzaniga, Bogen and their associates (1969, Levy, 1970, Bogen, 1969) have had a unique opportunity to study the specialization of the two halves of the brain isolated from each other. They worked with patients who had undergone surgical section of the corpus callosum for the treatment of epilepsy. These "split brain" patients were tested with special apparatus to insure unilateral presentation of the task. Sperry, Gazzaniga and Bogen have been able to establish that each hemisphere can function independently and is independently conscious. Learning and memory are found to continue separately in each hemisphere. The right hand literally does not know what the left hand is doing. Both halves independently sense, perceive and conceptualize. Unilateral associations between tactual, visual and auditory sensations remain. In these patients, the left hemisphere is capable of speech, writing and mathematical calculation, and is severely limited in problems involving spatial relations. The right hemisphere has use of only a few words and can perform simple addition only up to ten, but can perform tasks involving spatial relationships and music patterns.

It is important to emphasize that what most characterizes the hemispheres is *not* that they are specialized to work with different *types* of material, (the left with words and the right with spatial forms); rather each hemisphere is specialized for a different cognitive style; the left for an analytic, logical mode for which words are an excellent tool, and the right for a holistic, gestalt mode, which is particularly suitable for spatial relations as well as music. The difference in cognitive style is described in a recent paper by Levy, Trevarthen, and Sperry, 1972:

> "Recent commissurotomy studies have shown that the two disconnected hemispheres, working on the same task, may process the same sensory information in distinctly different ways, and that the two modes of mental operation involving spatial synthesis for the right and temporal analysis for the left, show indications of mutual antagonism (Levy, 1970). The propen- sity of the language hemisphere to note analytical details in a way that facilitates their description in language seems to interfere with the percep- tion of an over-all Gestalt, leaving the left hemisphere 'unable to see the wood for the trees'. This interference effect suggested a rationale for the evolution of lateral specialization . . ." (Levy, et al., 1972)

However, great caution should be exercised in making the inference of lateral specialization of cognitive function in normal people from lesion studies alone. One might consider whether the 'split' functions are due in some part to the radical surgery, or to other disturbances in these patients. The study of neurological disorders or surgical preparations casts light on normal functioning, but the most important and most practical question is whether the normal brain, engaged in everyday activities is organized around lateralization of cognitive function.

Recent research with normal subjects provides support for the inference that the intact brain does in fact make use of lateral specialization. With normal subjects, Filbey and Gazzaniga have measured the time required for information presented to one hemisphere to be acted upon by the other. A verbal reaction to information presented to the non-verbal right hemisphere took longer than a non-verbal response. (Filbey and Gazzaniga, 1969). McKeever found faster tachistoscopic word recognition for words projected to the left hemisphere (McKeever and Huling, 1970). In dichotic listening tasks, normal subjects have better recall for verbal material presented to the right than to the left ear and better recall for melodies presented to the left. (Kimura, 1961).

In the past three years we have applied electrophysiological methods to the study of this lateral specialization in normal people. By studying EEG asymmetry we were able to distinguish two cognitive modes as they occur in normal subjects using simple scalp recording (Galin and Ornstein, 1972). In brief, we examined the EEGs of subjects performing verbal and spatial tasks to determine whether there were differences in activity between the appropriate and inappropriate hemispheres. We recorded from the temporal and parietal areas since clinico-anatomical evidence indicates that these areas should be differently engaged in these tasks. We found that during verbal tasks the integrated whole-band power in the left hemisphere is less than that in the right, and during spatial tasks the integrated power in the right hemisphere is less than in the left. Most of the task-dependent asymmetry appeared to be in the alpha band. Our method of analyzing the ratios of right to left EEG power was adopted by McKee, Humphrey and McAdam (1973) in a study contrasting musical and verbal processing. They confirm our general finding that the ratio is higher in the verbal tasks compared to the non-verbal tasks.

Other laboratories have used electrophysiological techniques such as evoked potentials and DC potentials. Buchsbaum recorded averaged visual evoked potentials from the left and right occipital areas in response to words and geometric stimuli (Buchsbaum and Fedio, 1969). The responses to these two classes of stimuli were the same in the right hemisphere, but different in the left hemisphere. Wood et al. (1971) found similar results with auditory stimuli; subjects listened to verbal stimuli under two conditions; to process them for speech cues (stop consonants) and for non-speech cues (pitch). The evoked responses were the same in the right hemisphere, but different in the left hemisphere.

In summary, studies with brain injured, neurosurgical, 'split brain' and normal subjects confirm lateral specialization for cognitive function. Language processing and mathematical tasks depend heavily upon the left hemisphere while problems in spatial relations depend upon the right.

The lateralization of cognitive functions described above is characteristic of right handed people. The cerebral lateralization of left handed people is more complex. Hecaen (1964, 1971) bas provided an extensive review of the neurological literature and a summary of his own clinical studies, and concluded that left handers show a greater cerebral ambilaterality, not only for language, but also for gnosic and praxic functions. Hecaen distinguishes between left handedness which is familial and that which follows a perinatal injury to the left hemisphere. The familial type mayor may not have reversed language lateralization.

To our knowledge there have been no attempts to quantitatively evaluate the interaction between the verbal-analytic and spatial-holistic cognitive systems in normal daily activities. Our opinion is that in many ordinary activities normal people simply alternate between cognitive modes rather than integrating them. These modes compliment each other but do not readily substitute for each other. Although it is *possible* to process complex spatial relationships in words, it would seem much more efficient to use visual-kinesthetic images. For example, consider what most people do when asked to describe a spiral staircase; they begin using words, but quickly fall back on gesturing with a finger.

Processing in the inappropriate cognitive system may not only be inefficient; it may actually interfere with processing in the appropriate system. This 'interference hypothesis' is supported by a study of left-handed subjects who were presumed to have bilateral language representation (Levy, 1969). Levy compared left-handed and right-handed subjects with equal WAIS verbal scores and found that the left handers had significantly lower performance scores, which she attributed to interference from the presumed ambilaterality of language. Her observation has been confirmed by Miller (1971). Similarly, in a group of patients in whom right-hemisphere language was demonstrated with carotid amytal, Lansdell (1969) found a negative correlation between language ability and spatial performance scores. Brooks (1970) presents additional support for the hypothesis of "interhemispheric interference". Reading a description of spatial relations interferes with the subsequent manipulation of those spatial relations. Den Hyer and Barrett (1971) demonstrated selective loss of spatial and verbal information in short term memory by means of spatial and verbal interpolated tasks. Levy has in fact suggested that verbal and non-verbal functions evolved in opposite hemispheres to reduce interference of one system with the other (Levy, 1969).

Individual Differences in Brain Organization: Ceramicists and Lawyers

It is a common observation that some individuals seem to use a verbal analytic approach to problem solving while others use a holistic, spatial mode, even when this is not the optimum strategy. Our previous experiments show that the asymmetry in the EEG and in reflective eye movement reflects the lateralization of verbal and spatial cognitive processes *within subjects*. In this experiment we asked if these indices can be used to compare two individuals: for example, can we characterize one person as using the verbal-analytic mode more than another person. To test this hypothesis we selected subjects whose vocation places primary emphasis on the verbal-analytic or the spatial-holistic cognitive modes. For the verbal-analytic group we chose 18 lawyers and for the spatial-holistic group we chose 17 sculptors and ceramicists (artists engaged in three-dimensional forms and images).

In order to test whether these subject groups did in fact differ in cognitive mode as one would expect from their vocations alone, we evaluated the test scores from tasks which the subjects performed during the EEG recording sessions. These included two verbal performance tests (Writing-from-Memory and Text-Copying), two spatial performance tests (the Kohs Block Design and Mirror Drawing) and a preference test which we devised based on sorting by words and shapes.

Recordings were made from P3, P4, T3, T4, C3, C4, in the International 10–20 system all referred to Cz, while the subjects performed the cognitive tasks, and during an initial period of "attention-to-breathing". Each task lasted three minutes. The results are expressed as ratios of right hemisphere/ left hemisphere activity – a higher ratio means more left hemisphere cognitive activity.

The design of this experiment allows us to (a) look for confirmation of our previous findings of change in alpha asymmetry between cognitive tasks, (b) compare central (motor) leads with temporal and parietal leads, (c) compare memory and non-memory tasks, (d) compare lawyers and ceramicists with respect to their overall EEG asymmetry, and their ability to shift to the cognitive mode appropriate to the task at hand, (e) to study the correlation between a subject's level of performance on a task and his alpha asymmetry on that task, (f) to study the relative merits of reflective eye movements and the EEG measures as indicators of preferred cognitive mode. Here we present data on questions a-d.

Differences between Subjects:

TABLE I Individual differences in Cognitive Style:
Right/Left Alpha Ratios for Lawyers and Ceramicists[*]

	Blocks		**Write-from-Memory**	**Mirror Drawing**		**Text copying**
P4/P3 Ceramicists	1.00		1.16	1.02		1.06
Change		.16			.04	
Lawyers	0.99		1.22	1.01		1.08
Change		.23			.07	

[*] Geometric means over all subjects of EEG alpha power ratios (right/left).

	Blocks		Write-from-Memory	Mirror Drawing		Text copying
T4/T3 Ceramicists	0.76		1.05	0.75		0.91
Change		.29			.16	
Lawyers	0.79		1.19	0.75		0.96
Change		.40			.21	
C4/C3 Ceramicists	0.81		1.15	0.87		1.03
Change		.34			.16	
Lawyers	0.76		1.20	0.80		1.04
Change		.44			.24	

These results show that the difference between 'left' and 'right' hemisphere tasks is consistent and that the task-dependent asymmetry is greater in the group of lawyers than in the group of ceramicists (change score, Table I). This is true for both of the task pairs, and on all three of the electrode locations tested. To further examine the differences between subjects we analyzed the data *within each lead*, comparing paired tasks.

TABLE II Subject differences: Changes in alpha within each electrode location:
Each entry is the ratio of alpha power on the designated tasks.

		P3	P4	T3	T4	C3	C4
Blocks/Writing-from-Memory	Ceramicists	1.11	0.95	1.58	1.14	1.34	0.99
	Lawyers	1.16	0.94	1.92	1.27	1.62	1.03
	Ceramicists & Lawyers	1.14	0.95	1.75	1.2	1.47	1.01
Mirror Drawing/ Text Copy	Ceramicists	0.86	0.83	1.10	0.92	1.07	0.92
	Lawyers	0.97	0.91	1.29	1.00	1.18	0.91
	Ceramicists & Lawyers	0.92	0.87	1.19	0.96	1.13	0.92

We examined the change in alpha power at each electrode site by forming the ratio of alpha on the spatial task to alpha on the verbal task. (Using the ratio eliminates the effects of differences between subjects in absolute signal levels. We are only interested here in the change within subject). This analysis reveals differences between the two groups in the extent to which the EEG of the right, the left, or both hemisphere changes with the task. Table II shows that in all cases but one (MD/COPY on the parietal leads) *the groups differ in the engagement of the left hemisphere*; the lawyers show consistently greater change in left hemisphere alpha than do the ceramicists. Both groups show equal changes in the right hemisphere leads.

The data also indicate that for both groups the left hemisphere is more responsive to task demands – its alpha level changes more between tasks.

Reflective Eye Movements; an indicator of lateralized cognitive function and preferred cognitive mode

When people are asked a question requiring some reflection, they will usually avert their eyes briefly before answering (Day, 1964; Duke, 1968; Lib by, 1970). Previous studies, focusing on the lateral component of the eye movement, have indicated that the direction of a gaze shift may be related to the major cognitive mode of the person. For instance, Bakan (1969) reports that "left movers" tend to select a "soft" college major (e.g. arts and humanities), and "right movers" are apt to be more inclined to a science major and are relatively more adept at quantitive thought. This report was confirmed by Weiten and Etaugh (1973). Bakan and his associates relate this lateral directionality of eye movement to the asymmetry of the human brain; since activation of each of the cerebral hemispheres tends to produce orientation to the contralateral side of the body, it was suggested that a right eye movement indicated relatively greater activation of the left hemisphere and a left eye movement indicated relatively greater activation of the right hemisphere.

This supposition was strongly supported by our study (Kocel, et al., 1972) and that of Kinsboume (1972). Subjects were asked questions designed to evoke either verbal or spatial information processing (such as "Define the word economics", and "Which way does Lincoln face on a penny?") and the direction of subsequent reflective eye movements was recorded. We found more right lateral eye movements on verbal questions than on spatial questions, and concluded: 1) at least some individuals do show a reliable tendency to look more toward one direction, and 2) these individual tendencies can be strongly modified by the cognitive demands of the question.

Kinsboume also found more right movements on verbal than spatial questions, and in addition, found a significant difference in the vertical dimension; spatial questions elicited more up movements than verbal questions. In this experiment we studied the reflective eye movements in both vertical and horizontal dimensions in our groups of lawyers and ceramicists to determine to what extent the EEG and eye movement indices reflect the same cognitive processes. From the report by Bakan one would expect ceramicists to make more left reflective movements than lawyers. From Kinsboume's report of an association between spatial processing and up movements, one might also expect the ceramicists to make more UP movements than the lawyers. In addition to the across-subject comparison between ceramicists and lawyers we sought to replicate on these specially selected groups two previous findings: for each subject, 1) more right movements are evoked by verbal questions than by spatial questions, 2) more up movements are evoked by spatial than by verbal questions. In a second experiment, these effects of question type were again studied using a non-specialized population and a modified question set.

In summary, the results of Experiment I show that the lawyers and ceramicists differ in their reflective eye movements (Table III). The difference appears in the vertical dimension; ceramicists make more UP and fewer DOWN movements than do the lawyers. We did not find differences in lateral eye movement between these groups, contrary to expectations from our previous research and from that of Bakan and of Kinsboume. We have no explanation for this.

Taken together, the results of Experiment I and 2 show that question type also affects reflective eye movements. This effect is seen in both the vertical and lateral dimensions; verbal questions elicit more DOWN and RIGHT movements and fewer STARES than do spatial questions. There is an internal consistency in the distribution of vertical eye movements analyzed by vocational group and by question type; a higher percentage of UP movements is associated with the ceramicists and with the spatial questions, and a higher percentage of DOWN movements is associated with the lawyers and verbal questions.

TABLE III All Questions Ceramicists vs. Lawyers

	Lateral Movements				**Vertical Movements**				
	L	**NLM**	**R**	**R-L**	**U**	**NVM**	**D**	**U-D**	**NM**
Ceramicists N=17	26.0	23.3	50.4	24.4	33.0	50.6	16.2	16.8	19.6
Lawyers N=18	28.0	24.8	46.9	18.8	19.4	49.7	30.7	-11.2	18.9
$p^{*}<$	ns	ns	ns	ns	.0005	ns	.0001	.0001	ns

TABLE IV Effect of Question Type

Experiment 1 Ceramicists and Lawyers combined (N=35)

	Lateral Movements				**Vertical Movements**				
Question Type	**L**	**NLM**	**R**	**R-L**	**U**	**NVM**	**D**	**U-D**	**NM**
Neutral	31.6	21.5	46.7	15.0	26.7	49.5	23.5	3.1	17.0
Spatial	24.6	30.1	45.0	20.4	28.4	53.8	17.6	10.7	25.9
Verbal	24.8	20.6	54.3	29.4	23.5	47.1	29.1	-5.6	14.9
$p^{*}<$	ns	.001	ns	ns	ns	ns	.04	.09	.04

Experiment 2 Non-specialized Subjects (N=19)

	Lateral Movements				**Vertical Movements**				
Question Type	**L**	**NLM**	**R**	**R-L**	**U**	**NVM**	**D**	**U-D**	**NM**
Spatial	25.0	41.9	33.0	8.0	38.5	56.3	5.1	33.4	33.3
Verbal	27.5	26.3	46.1	18.5	32.6	53.7	13.5	19.1	19.2
$p^{*}<$	ns	.001	.003	.09	ns	ns	.08	.06	.0003

[*] All p values two-tailed ns=p> .10

EEG Feedback Training; Voluntary control of EEG asymmetry

We have done pilot work in training individuals to voluntarily control their EEG asymmetry. Initially, we used a system in which the ratio of EEG alpha right/left controlled the loudness of a tone signal. Subjects were not able to learn to control this signal, perhaps because alpha level was confounded with alpha amplitude; e.g. if the initial alpha levels were 150uv and 100uv, then the ratio would be 1.5; if the alpha on each side then decreased by the same amount, say 50uv, the ratio would now be 100uv/50uv, or a ratio of 2.0, and the tone would get louder. To eliminate this confounding, we developed a system which preserves both level and ratio information, and takes advantage of the basic organization of the cerebral hemispheres to orient to the contralateral half of space. The integrated output of each EEG channel (for example, P3, P4) controls the loudness of a tone which is fed to the contralateral ear of the subject. This binaural feedback gives a spatial illusion, with the sound appearing to move from the center to the left or the right as the ratio of P4 to P3 goes over or under one. The loudness indicates the absolute level of activity, and the spatial location indicates the ratio of one side to the other. Given this information subjects are asked to "make the sound loud, and move it to the left" or to the right. Four out of four subjects run on this paradigm for ten sessions have been successful in voluntarily altering their asymmetry index by at least as much as the change elicited by our right and left hemisphere tasks. Two of the subjects who can reliably control the parietal asymmetry day after day have also worked with temporal lead feedback, and report that this is very different from working with the parietals; the "mental gymnastics" they used to control the parietal asymmetry were not effective for the temporals. This indicates that our technique may be sensitive to intra-hemispheric specialization for cognition; for example, the parietal areas for tasks depending on visual guidance, the temporals for tasks involving memory, the central leads for tasks with motor output.

A CONCLUSION

Previous investigators have sought to relate electrophysiological recordings to cognitive functions. A major effort has been devoted to relating the EEG to "intelligence" (see review by Vogel, et al., 1968). Our approach to this problem takes into account three factors which seem to have been neglected in the past. I. Recording while the subject is engaged in a task, rather than trying to relate a "resting" EEG or averaged evoked potential to subsequent performance. 2. Selection of cognitive tasks which clinical evidence has shown to depend more on one hemisphere than the other, and which therefore should be associated with a predictable distribution of brain activity. 3. Selection of electrode placements on clinico-anatomical grounds. A wealth of evidence suggests that temporal and parietal leads should be the most functionally asymmetrical, and occipital leads the most similar. Unfortunately, occipital leads have been used most often in the past, probably because they are not as sensitive to eye movement and muscle artifacts. Usually recordings have been made only unilaterally.

Now that we have established a method for determining lateralization of cognitive function in normal subjects, we intend to study several major areas of concem: the generality of lateral specialization of cognitive function in the population, the role of lateral specialization in critical academic skills, the effect of social drugs on hemispheric interaction, and the possibility of training voluntary control over patterns of lateral asymmetry using the feedback EEG.

The division of cognition into major modes (verbal-analytic and spatia1 holistic) was suggested by considering the anatomical division of the brain into two specialized hemispheres. We have been able to distinguish between these two cognitive modes as they occur in normal subjects, by using simple scalp recordings. Our theoretical approach and experimental data provide a means of integrating research in clinical neurology, cognitive psychology and electrophysiology.

Relationships between brain states and cognitive activity

Our development of an EEG index of lateralized functions may enable the training of ordinary individuals to achieve more precise control over their brain's activity. Instead of training "alpha control" or "theta control", it may be possible to train functionally relevant patterns of activity.

The EEG measure may be used clinically to assess the localization of language. This would be useful to neurosurgeons who currently have to rely on the intracarotid injection of barbiturates. A less heroic method of localizing language would have wide application in diagnosis and research in the areas of "minimal brain dysfunction", dyslexia and developmental neuropsychology.

The evidence cited above of interference between the right and left cognitive modes provides a new kind of support for the hypothesis of Orton, that lack of cerebral lateral specialization plays a major role in dyslexia and stuttering. This hypothesis has continued to sustain interest, in spite of a lack of convincing direct evidence. Until recently, the only generally available index of cerebral lateralization was handedness, and people with little hand preference, or left handers who were "switched" or those with mixed hand and eye preference were considered to be “high risk”. The incidence of such people in clinical categories such as stuttering, dyslexia and specific learning disability is usually found to be higher than in the normal population.

Our EEG method for studying lateralization of cognitive function, along with the dichotic listening test, can provide a much more direct and presumably more sensitive means for investigating disorders of laterality than measures based on hand, eye or foot dominance. Our present proposal to extend our measures to left handed and ambidexterous populations will lay the groundwork for these clinical studies.

Our EEG and eye movement studies provide potential methods of assessing an individual’s preferred cognitive mode. An individual’s preferred cognitive style may facilitate his learning of one type of subject matter, e.g., spatial, relational, and hamper the learning of another type, e.g., verbal-analytical. A student’s difficulty with one part of a curriculum may arise from his inability to change to the cognitive mode appropriate to the work he is doing.

Studies by Cohen (1969) and by Marsh, *et al.,* (1970) have indicated that subcultures within the United States are characterized by a predominant cognitive mode: the middle class is likely to use the verbal-analytic mode; the urban poor is more likely to use the spatial-holistic mode. This results in a cultural conflict of cognitive style and may in part explain the difficulties of the urban poor children in the school system oriented toward the middle class. There seems to be a new recognition among educators of the importance of both modes of experiencing the world (J. Bruner, *On Knowing: Essays for the Left Hand*, 1965). Many new programs (e.g. “Sesame Street”) emphasize helping verbal-analytically oriented children to develop holistic mode skills as well as helping holistically-oriented children to make use of the traditional verbal-analytic materials. If our project is successful, it may make it feasible to train an individual child to enter both cognitive modes appropriately. With EEG feedback an individual may be able to learn to sustain a pattern of brain activity and the concomitant cognitive mode which is appropriate to reading and arithmetic on the one hand and painting and construction on the other.

Developmental studies of lateralization of cognitive function

This approach may also be of use in the study of cognitive development. Since brain injuries before the age of 12 rarely result in permanent aphasia, it is reasonable to suppose that the lateralization of cognitive function is still in flux in young children after the acquisition of speech and even after the acquisition of written language. The maturation of the child's cognitive power may be paralleled by, and perhaps even depend upon, increasing lateral specialization with a resulting decrease in interference between cognitive systems. EEG measures of cognitive functioning could be powerful tools for mapping the course of this growth. These measures could be used in diagnosing aberrations in cognitive development. For example, certain forms of dyslexia may be caused by interhemispheric interference. Perhaps "feedback" training to improve selective inhibition of the inappropriate cognitive mode would prove useful in therapy.

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