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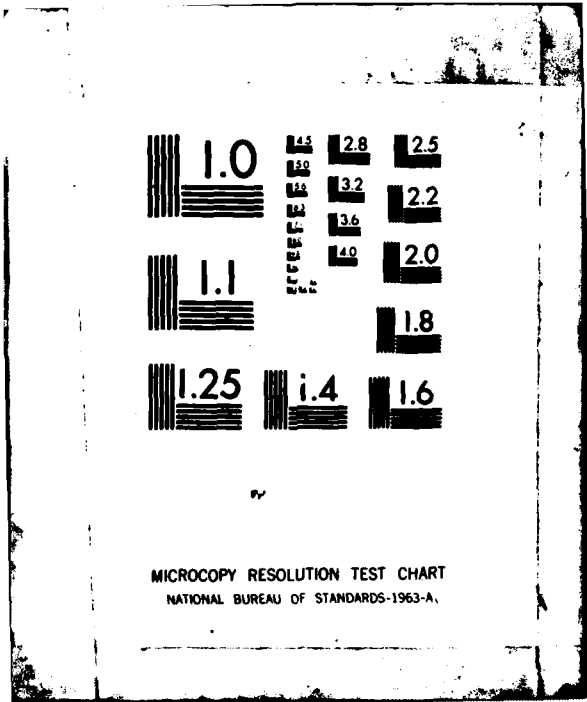
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INTENSITY RATIO, COHERENCE AND PHASE OF EEG
DURING SENSORY FOCUSED ATTENTION*

David J. Hord†

Naval Health Research Center
P.O. Box 85122
San Diego, CA 92138-9174

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†Research Psychologist, Environmental Physiology Department

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INTRODUCTION

As part of this laboratory's effort to identify electrophysiological predictors of performance decrement, three measures of ongoing electroencephalographic (EEG) activity were examined as possible correlates of focused attention. By focused attention is meant the particular sensory input (visual or auditory) that is being processed at the moment the EEG is sampled. The three EEG measures were the intensity ratio, coherence, and phase.

Intensity ratios of paired EEG sources have been used in several studies of hemispheric asymmetry. An example of an attempt to relate asymmetry to reaction time was the study by Glass and Butler (1977). They concluded that the left/right ratio of alpha intensity increases as reaction time increases. There have been fewer studies of the relation of EEG coherence to cognitive variables. Busk and Galbraith (1975) used a derived weighted average coherence from 4 scalp locations to study the relation between coherence and performance. They concluded that coherence was proportional to task difficulty.

A study of the relation of EEG asymmetry to task and sex by Beaumont, Mays and Rugg (1978) used the same variables selected for the present work: intensity ratios, coherence, and phase of alpha. Their results were interpreted to mean that spatial tasks, as compared to non-spatial tasks, are associated with increases in coherence in the right hemisphere. With respect to phase angle measures of asymmetry, they reported a significant sex by task interaction but subsequently drew attention to the caution that must be exercised in their interpretation, since phase angle data can only be viewed as valid if the corresponding coherences are sufficiently high.

There have been several attempts to use the phase relationship between pairs of EEG sources as a parameter of human brain activity. Using other techniques, the stability of alpha phase relationships has been reported to be dependent on vigilance level (Darrow, 1964). Vos, Sholten and Van Worden (1975), however, reported no success in finding a significant phase difference between symmetrically placed bipolar derivations. A cross-correlation study of alpha by Liske, Hughes, and Stone (1967) reported a mean time difference for resting adult males of 0.83 msec in which the right (P_4-0_2) leads the left (P_3-0_1). If an alpha frequency of 10 Hz is assumed, this translates to 3° of mean phase difference. The distribution of phase angles, however, was obtained from 2.5-minute resting samples which might be far too long to reflect a constant psychological "set". Adey (1970) reports that the psychological "set" of a particular behavioral state is very short, on the order of one or two seconds. In support of Adey's premise, Hoovey, Heineman and Creutzfeldt (1972) completed an analysis of right-left occipital alpha trains and concluded that one side leads for a time and then the other. Such periods were about 3 to 5 seconds long. Gevins and Schaffer (1980) have recently reinforced a critical attitude toward the conclusions drawn of the relationship of EEG measures to cognitive variables. They cite a number of methodological and design flaws that warrant caution in making general statements of the EEG-cognition functional relationship. Notable among these flaws is the assumption that a constant perceptual state exists for the duration of the EEG measurement period.

Attempts to relate brain electrophysiology to behavioral states thus may be confounded by rapidly fluctuating states of attention, leading to large variances in the various measures of brain activity. The stimulus that evokes an event-related potential or the time epoch chosen for EEG spectral analysis may occur during any one of several possible states of attention and/or during their transitions.

In previous work (Hord et al., 1974) mean intrahemispheric phase relationships were found to be reasonably stable during an EEG self-regulation task. The stability was attributed to the nature of the task which assumed continuous, but passive, attention to a contingent auditory feedback signal. It was concluded that the temporal relationship between the left occipital and frontal alpha was such that the former led the latter by approximately 42 msec under the conditions of self-regulation. In the present study, an attempt was made to stabilize phase angle measurements by forcing continuous attention on a sensory discrimination task, involving a slowly changing stimulus parameter. The purposes of this study were to:

1. Develop a performance task that focuses the subject's attention on a simple sensory discriminant.
2. Measure the three parameters of ongoing EEG (intensity ratio, coherence, and phase) during short time epoch immediately preceding subject's discrimination responses.
3. Determine the extent to which the EEG measures differentiate sensory mode (visual or auditory).
4. Determine the extent to which the EEG measures predict performance on the two sensory tasks.

METHOD

Control of attention was accomplished in two ways: (1) the task involved slowly changing stimulus parameters preceding a contingent response so that continuous attention in a particular sensory mode could be assumed; (2) "Evoked Spectral Analysis" (Elazar and Adey, 1967) was used to obtain ensemble-averaged auto and cross spectra, which have been shown to be relatively stable when based on short time epochs. The intensity ratios, coherences and phase angles were then derived from these averaged values. The intensity ratio is the ratio of spectral intensity at 10 Hz obtained from pairs of intra and interhemispheric scalp electrodes. It is used as a measure of cerebral dominance in the present study. Coherence is a measure of the relationship between two sinusoidal signals and is conceptually similar to the common product-moment correlation coefficient. The phase angles were derived from components of the coherence analysis and are expressed in terms of degrees. The greater the phase angle between two EEG sources, the greater the time (lead or lag) between the appearance of a given portion of the sinusoid at one electrode and subsequent appearance of that portion at the other electrode. For a given frequency, say 10 Hz, the phase angle can be directly converted to milliseconds. For the present analysis, EEG samples were drawn from the 2-second period immediately preceding subjects' responses. The choice of a 2-second measurement period was based on consideration of Adey's premise that attention may shift every few seconds. A short time epoch would be necessary if the focus of attention is going to be assumed to be constant.

Ten volunteer subjects each completed 20 trials of a visual and 20 trials of an auditory decision task. EEG signals from F_1 , F_2 , C_3 , C_4 , O_1 , O_2 , referenced to linked mastoids, were recorded continuously on a Beckman Dynograph and HP 3900 tape recorder using a 0.1 sec time constant. The subjects sat at a "Sonar Simulator Console" for the duration of the visual and auditory tasks which lasted 25 min each. The center of the console contained a 9-inch TV monitor for the presentation of the visual task. The auditory task was presented over earphones. Subjects' verbal responses to the decision task were recorded by microphone on the tape and polygraph record. The onset of each verbal response served as a reference point for the computer analysis of EEG. Subjects' eyes were open for the duration of both tasks. They were instructed to blink or move their eyes as little as possible, especially during the decision-making period.

Visual and Auditory Decision Tasks

Since it was important to control subjects' attention during the EEG recording period, tasks were used in which focused attention was required for several seconds.

On each of the 20 trials for the visual task, the subject viewed two white disks, 9 cm in diameter, separated by 1 cm. At the beginning of a trial the disks were of equal luminance. As the trial progressed, one or the other of the disks (by random selection) gradually diminished in luminance at a rate such that it was less than half the original luminance after approximately 30 sec. The subject had been instructed to verbalize the side ("right" or "left") on which the changing disk occurred as soon as he was "reasonably sure". The verbal decision moment recorded at the microphone was subsequently used as the reference point for EEG analysis. The assumption was made that subjects' attention was focused on the visual stimulus during the 2 or 3 sec epoch immediately preceding the decision moment.

On each of the 20 trials for the auditory task, the subject listened to 1 KHz continuous pure tones of equal intensity in each ear at the start of a trial. As the trial progressed, the tone presented to one or the other ear gradually decreased in pitch. The frequency of the tone on the changing side was at .9 KHz after approximately 30 sec. The subject had been instructed to verbalize on the microphone the side ("right" or "left") on which the changing tone was occurring as soon as he was "reasonably sure". As with the visual task, the assumption was made that the subjects' attention was focused on the auditory stimulus for at least 2 or 3 sec prior to the decision moment.

The intertrial interval for all trials was approximately 10 sec. The entire sequence of 20 trials for the visual task and for the auditory task was prerecorded on video cassettes, along with detailed instructions. The order of presentation of the visual and auditory tasks was random over subjects.

EEG Analysis

EEG from the six scalp electrodes was recorded on an analog instrumentation tape at 1-7/8 ips for the duration of each task. Decision moments were then obtained for each trial from the time code on the polygraph. Two-second samples preceding each decision moment were digitized at 125 samples per sec on a PDP-12 computer and stored on Linc tape. Calibration of EEG for spectral

analysis was achieved by adjusting the analog signals to predetermined levels prior to digitization. A calibration constant for each EEG lead within each subject task was determined with a pre-recorded 10 Hz, 50 μ V (100 μ V peak-to-peak) sine wave. The calibration signal was adjusted to maintain an intensity ratio of 1.00 for all comparisons. A calibration of the phase angle analysis was achieved by artificially phase-shifting comparisons between adjacent channels by 90 degrees. Computer analysis of the phase-shifted calibration signal confirmed that the signal was in fact shifted 90 degrees. Phase was defined as the arctan [Quads/Cosp], where Quads is the imaginary and Cosp the real components of the cross spectrum (Walter, 1963).

Spectral analysis was accomplished with a Fast Fourier Transform, yielding auto and cross spectra with 0.5 Hz resolution and frequency range from 0.5 to 19.5 Hz. These spectra were then ensemble-averaged across the 20 trials for each subject-task to yield the averaged spectra. Averaged coherence and averaged phase were derived from the cross spectral components. A measure of cerebral dominance, labeled the intensity ratio, was determined for intra- and interhemispheric comparisons of averaged autospectra. The ratio was equal to the intensity of 10 Hz EEG at one site divided by the intensity of 10 Hz EEG at another. The intensity ratio, therefore, was equal to 1.00 for the condition in which the intensity at the two sources was equal. The ratio was greater or less than one as the left or right (or front or back) respectively, became proportionately greater. Two EEG analyses were completed for each of the 10 subjects, one for the visual task and one for the auditory task. Each spectral analysis was based on a total of 40 seconds distributed across 20 trials at 2 sec per trial. In this procedure, the "signal" (e.g. sensory modality) was enhanced over the background EEG "noise" similar to response averaging of the stimulus dependent evoked potential from background EEG.

RESULTS

The ensemble averaged intensity ratios, coherences, and phase angles at 10 Hz for each subject are given in Table I for the visual task, and Table II for the auditory task. Group means and standard deviations for each EEG pair are also presented. (See page 7.)

The group mean interhemispheric intensity ratios are all less than 1.00 and the intrahemispheric ratios are all greater than 1.00, suggesting that intensities tend to be greater in the right hemisphere and in the frontal as opposed to occipital regions. Individual t-tests for the independent conditions show that the group means are not significantly different from 1.00 in each case, however. Differences between visual and auditory task also are not different by repeated measures analysis of variance.

The maximum coherence occurred between F_1 and F_2 for both the visual and auditory tasks. The lowest sample mean coherence occurred in the F_2 to O_2 comparison for both the visual and auditory tasks. None of the comparisons between sensory modes are significant for the coherence measure.

The distributions of phase angle tend to show high variability for both visual and auditory conditions in spite of careful experimental design considerations chosen specifically to reduce the variance. The F_1 to O_1 comparison for the auditory task is significantly negative, ($t = 2.145$,

p<.05). All other tests within sensory mode, and all comparisons between sensory modes are not significant.

TABLE I
INTENSITY RATIO, COHERENCE, AND PHASE FOR THE VISUAL TASK

s	INTENSITY RATIO					COHERENCE					PHASE				
	F_1/F_2	C_3/C_4	O_1/O_2	F_1/O_1	F_2/O_2	F_1-F_2	C_3-C_4	O_1-O_2	F_1-O_1	F_2-O_2	F_1-F_2	C_3-C_4	O_1-O_2	F_1-O_1	F_2-O_2
Wh	.33	.63	.46	1.00	1.34	.79	.60	.60	.25	.07	5.73	-10.80	-12.86	27.60	-27.90
Ga	.26	.49	.71	2.41	6.02	.81	.06	.69	.01	.06	5.98	13.06	-4.96	-11.53	-49.09
Lu	.15	1.03	.77	.97	4.92	.60	.77	.89	.21	.06	-8.30	-6.92	-5.63	-10.07	-15.71
So	1.26	1.44	.81	1.15	.73	.77	.29	.69	.14	.22	4.95	-12.15	6.80	-27.73	-28.50
Wo	1.57	1.29	1.76	1.13	1.26	.76	.06	.63	.02	.03	.76	3.81	-19.72	-178.55	155.50
Mi	.56	.56	.65	1.17	1.80	.86	.31	.53	.24	.13	-6.14	1.28	-3.79	-129.30	-92.74
Bi	.81	1.85	.73	1.17	1.05	.90	.29	.57	.08	.00	-2.63	-17.88	-7.63	73.52	-
Ru	1.53	.33	2.07	1.03	1.66	.85	.21	.32	.05	.06	-6.58	-4.92	-11.37	70.50	71.96
Mc	.77	.85	.85	.91	1.01	.68	.06	.77	.10	.06	21.84	16.00	-3.20	42.00	2.57
Or	.62	.84	.85	.98	.90	.75	.02	.61	.20	.16	-11.07	55.32	6.89	-59.73	-22.73
M	.79	.93	.94	1.19	2.07	.78	.29	.63	.13	.09	.46	3.88	-5.59	-20.33	-73
SD	.50	.48	.53	.44	1.84	.09	.25	.15	.09	.06	9.70	21.13	8.16	82.96	73.08

TABLE II
INTENSITY RATIO, COHERENCE, AND PHASE FOR THE AUDITORY TASK

s	INTENSITY RATIO					COHERENCE					PHASE				
	F_1/F_2	C_3/C_4	O_1/O_2	F_1/O_1	F_2/O_2	F_1-F_2	C_3-C_4	O_1-O_2	F_1-O_1	F_2-O_2	F_1-F_2	C_3-C_4	O_1-O_2	F_1-O_1	F_2-O_2
Wh	1.61	.21	1.39	.27	.23	.62	.96	.91	.92	.45	52.85	58.83	-149.62	-14.62	129.54
Ga	.16	.94	.74	.97	4.36	.73	.43	.74	.11	.05	6.67	-2.76	-11.97	-62.13	-80.20
Lu	.22	1.40	.76	1.83	6.32	.77	.76	.75	.09	.07	4.83	1.82	-4.27	-3.83	13.84
So	1.72	.64	2.05	1.40	.82	.82	.32	.73	.39	.46	-3.70	16.56	5.26	-3.69	-9.65
Wo	.94	.97	.68	2.96	2.13	.68	.03	.68	.07	.01	-6.59	-3.90	-5.79	-67.75	-28.23
Mi	.72	.62	.70	.53	.67	.87	.42	.82	.51	.86	-8.23	-12.41	-11.42	-165.93	-100.80
Bi	1.29	.21	1.32	.73	.72	.68	.63	.33	.67	.23	36.42	54.30	-137.89	-12.21	124.49
Ru	.84	.37	.34	.62	.25	.94	.30	.49	.00	.00	-4.00	3.71	1.76	-	-
Mc	.57	.66	.77	1.32	1.78	.89	.40	.76	.18	.17	1.90	-13.83	-9.05	-36.43	-54.94
Or	.88	1.09	.89	.70	.71	.91	.20	.53	.00	.18	1.80	12.14	-3.46	-	-124.80
M	.86	.80	.80	1.20	1.86	.79	.44	.67	.29	.22	8.18	11.46	-32.85	-44.57	-21.17
SD	.53	.46	.32	.84	1.99	.11	.27	.17	.32	.22	20.18	25.90	98.87	51.53	100.10

DISCUSSION

The observation that the group mean left hemisphere intensity is less for all leads and conditions on both visual and auditory tasks (all ratios are less than 1.00) would be consistent with the report by Butler and Glass (1974) for verbally mediated tasks. The lack of a significant effect within columns suggests that a generalization of their observation for visual and auditory tasks cannot be made, however. For tasks that involve attention to sensory input, the present data cast doubt on the existence of alpha suppression in the left hemisphere across subjects.

The intrahemispheric comparisons in the frontal and occipital areas ($F_1/O_1, F_2/O_2$) show consistent suppression of the occipital EEG for both tasks. Four out of four comparisons are values greater than 1.00. Since the differences between visual and auditory tasks are not significant, this relative suppression in the occipital area may be due to the general features of the task, i.e., the continuous attention required for correct decisions.

The mean phase angles for the visual and auditory tasks are not significantly different from each other for any of the EEG leads. The distributions tend to have large standard deviations. A negative phase angle for the interhemispheric occipital leads (O_1-O_2) occurs in 8 of the 10 subjects for both visual and auditory tasks and may warrant further examination. The negative phase angle may mean that O_1 lags O_2 . There does not appear to be any difference between visual and auditory tasks in this regard.

The mean intrahemispheric (F_1-O_1, F_2-O_2) phase angles are all negative, with the left hemisphere becoming significantly negative during the auditory task. This negative phase angle might mean that the occipital leads the frontal during the auditory task. But the amount of lead is quite variable, ranging from 3.69 degrees to 155.93 degrees. The results are, therefore, not very consistent with the earlier study (Hord, et al., 1974) that reported phase angles of the order of 20 degrees. The difference may be a reflection of the nature of the task. The decision task in the present study emphasizes focused attention and is different in that respect from the passive listening that occurred in the previous study.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Intensity ratios, coherence and phase relationships of 10 c/sec EEG among six scalp locations were obtained from 20 subjects during focused attention on visual and auditory decision tasks. The analysis was based on 2 sec epochs immediately preceding subjects' decisions, in which gradually changing stimulus parameters led to a decision, as opposed to the usual sudden onset stimulus presentation. It was assumed that the subjects' attention was maximally focused on the information content of the stimulus during this period.		

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20. Abstract (continued)

The distributions of intensity ratio, coherence and phase were ensemble-averaged across trials to reduce their variances. The results suggest that during focused attention, the intensity ratios and phase angles do not differentiate sensory mode, but that right fronto-occipital coherence may be less during visual attention than auditory attention. Furthermore, the left hemisphere shows a negative phase angle during the auditory task but not the visual, although the distribution of phase angles is highly variable across subjects. The phase angles obtained in this study are contrasted with those obtained in a previous study in which passive, as opposed to focused, attention was maintained.

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