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Neuropsychological Correlates of the Electroencephalogram in Epileptics: II. The Waking Posterior Rhythm and its Interaction with Epileptiform Activity

Carl B. Dodrill and Robert J. Wilkus

Seizure Clinic, Department of Neurological Surgery, and Division of Electroencephalography and Clinical Neurophysiology, Department of Laboratory Medicine, University of Washington School of Medicine, Seattle, Washington 98195

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Investigators who have studied electroencephalographic rhythms and abilities have rather strikingly failed to reach a consensus about their interrelationships. Some have concluded that certain EEG rhythm parameters are positively related to abilities (Vogel and Broverman, 1964; Vogel and Broverman, 1966; Tarter, 1972), others have doubted the existence of a general relationship (Lindsley, 1944; Ostow, 1950; Ellingson, 1956; Ellingson, 1966), and one could not come to a firm conclusion (Walters, 1964). Factors undoubtedly contributing to the confusion include (1) use of subjects from diverse populations ranging from normals to the obviously brain damaged and from children to adults; (2) use of tests which rarely assessed abilities outside the area of "intelligence"; (3) a constricted assessment of EEG rhythms with excessive emphasis upon the alpha rhythm as a primary EEG variable; and (4) differences in EEG recording techniques which make many studies not directly comparable. Mundy-Castle (1958) and Vogel and Broverman (1964) have discussed the implications of such factors and have suggested that a tendency to limit both the psychological and the EEG variables examined may be at least partially responsible for the inconclusive findings.

Giannitrapani (1969) took some steps to remedy this situation by examining a broad range of rhythms (6-50 Hz) from several areas of the scalp (frontal, temporal, parietal, and occipital) in normal adults. In the area of abilities, he limited himself to a study of intelligence, but provided a fairly diverse assessment of it by means of the Wechsler Adult Intelligence Scale (WAIS). He was able to demonstrate statistically significant relationships between summary scores of the WAIS and various EEG indices obtained from the parietal and occipital areas in particular. In epileptics, Vislie and Henriksen (1958) and Lennox and Lennox (1960) conducted less detailed studies which showed that slow and disturbed rhythms are associated with lower than normal intelligence. Similar findings also have been reported with respect to brain injured and mentally deficient individuals (Vogel and Broverman, 1964), but again little appears to have been done outside the area of intelligence.

This study was designed to investigate the relationships between a battery of neuropsychological measurements and the posterior dominant waking EEG rhythm of uncontrolled epileptics. Unlike most previous studies, no attempt was made to limit this research to EEG activity within the alpha band (8-13 Hz). In

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addition, a broad range of abilities was assessed by an entire battery of tests rather than by a single measure. Furthermore, the opportunity was available to determine possible interactions between the frequency of this posterior EEG rhythm and the presence or absence of EEG epileptiform activity in relation to abilities. In this way, it was possible to examine neuropsychological correlates of some basic EEG variables in a manner complementary to the studies by Wilkus and Dodrill (1976).

MATERIALS AND METHODS

The patients, neuropsychological tests, and EEG techniques for this study were the same as those reported by Wilkus and Dodrill (1976) and will not be described in detail here.

EEGs were evaluated with regard to their dominant waking parieto-occipital rhythm. This was counted for 10 consecutive sec in three different representative segments of each recording either from one or both sides of the head with the patient resting and the eyes closed (Wilkus and Green, 1974). Random faster or slower potentials apparently mixed with, but not obscuring, this activity were disregarded. The figure obtained was averaged and rounded to the nearest 0.1 Hz. The findings were very similar to those obtained by counting the same activity during a few seconds of maximal expression as would be done for routine clinical interpretation. Reliability of this procedure was checked blindly by reassessing 10 randomly selected recordings and resulted in a correlation coefficient of 0.88, a mean error of 0.3 Hz, and a maximum error of 0.9 Hz. Evaluation of epileptiform activity followed the procedure already described (Wilkus and Dodrill, 1976).

For the principal analysis, patients were arranged according to their dominant posterior rhythm frequency (DPRF) from lowest (5.1 Hz) to highest (11.0 Hz). This distribution was divided into approximate thirds resulting in a DPRF Low group (5.1-7.7 Hz) of 31, a DPRF Medium group (7.8-8.7 Hz) of 29, and a DPRF High group (8.8-11.0 Hz) of 30 subjects. One-way analysis of variance was applied across these groups for each neuropsychological variable. In order to facilitate comparisons of results, raw score data were converted into normalized T scores having a mean of 50 and a standard deviation of 10. To assess differences between groups having significant overall F statistics, the Neuman-Keuls procedure with unequal Ns was employed (Winer, 1971).

In a second analysis, the combined relationships of DPRF and presence or absence of EEG epileptiform discharges (ED) with psychological performance were assessed. Patients were arranged into DPRF Low (5.1-8.2 Hz) and DPRF High (8.3-11.0 Hz) groups. These were then divided according to whether or not ED were present, resulting in four groups: (1) DPRF Low, ED Present (N = 29); (2) DPRF High, ED Present (N = 29); (3) DPRF Low, ED Absent (N = 16); and (4) DPRF High, ED Absent (N = 16). These data were analyzed with regard to each neuropsychological variable by means of a two-way analysis of variance procedure which permitted the assessment of DPRF and ED separately as well as their possible interactions.

All patients were taking diphenylhydantoin as their sole anticonvulsant medication at the time of evaluation. In order to assess possible effects of medication on the DPRF, serum diphenylhydantoin levels were determined for all patients (Green et al., 1973). Means (and standard deviations) in micrograms per milliliter of serum for the groups were as follows: DPRF Low = 33.53 (16.84); DPRF Medium = 32.41 (14.29); and DPRF High = 22.65 (13.09). Analysis of variance applied to these data resulted in an overall F statistic of 4.89 which was significant at the 0.01 level. Thus, slower rhythms were generally associated with higher serum diphenylhydantoin levels.

Finally, possible differences across the groups within each of the three analyses were evaluated with respect to the variables of age, education, age at onset of seizure disorder, duration of disorder, and total number of seizures in the 30 days prior to evaluation. In no instance did a difference appear on any of these variables which was statistically significant at the 0.05 level or greater.

RESULTS

Results of the basic one-way analysis of variance of the Low, Medium, and High DPRF groups are presented in Table 1 and Fig. 1. In this and succeeding tables, raw score information is presented, but in order to meet statistical assumptions underlying the analysis of variance, all F statistics were derived from T scores. All figures present data in T score form and permit a visual perspective for the results overall. Examination of Table 1 and Fig. 1 reveals that the DPRF Low group consistently did worse on all tests than either the Medium or the High DPRF group and that the High group usually did just a little better than the DPRF Medium group. Many statistically significant differences in neuropsychological test results occurred between the Low and the other two DPRF groups, but only rarely between the Medium and the High groups. The Impairment Index which summarizes a number of tests was associated with the largest overall F statistic.

Table 2 and Fig. 2 present the data analysis involving rhythm (DPRF Low, DPRF High) and EEG epileptiform activity (ED Present, ED Absent). With the data grouped in this fashion, fewer statistically significant differences were demonstrated with respect to the DPRF variable, but a very large number of such relationships were found dependent upon presence or absence of ED. However, only one significant interaction effect was present.

DISCUSSION

This investigation has demonstrated a number of statistically significant relationships between the EEG waking DPRF and neuropsychological abilities. In every instance, measures related to the DPRF were complex and required considerable attention to the task. When either the complexity or the attentional aspect was missing on a neuropsychological test, a statistically significant relationship failed to appear. Thus, no relationships appeared with the Category Test despite its complexity and none with the Speech Perception Test despite its attentional requirements. This was true even though the sensitivity of these tests to brain functioning has been clearly established (Reitan, 1955).

In our study, intelligence scores rarely attained statistical significance even though they consistently improved as DPRF increased. This finding is presumably related to the nature of the WAIS compared to the other tests. The Verbal part of the WAIS requires much recall of long-term memory with only modest mental

TABLE 1. *Means, standard deviations, and F statistics of neuropsychological tests on patients grouped according to low (5.1-7.7 Hz), medium (7.8-8.7 Hz), and high (8.7-11.0 Hz) DPRF*

	Groups						
	Low		Medium		High		
Test variable	Mean	SD	Mean	SD	Mean	SD	F statistics
Category Test	65.87	31.46	55.34	28.03	53.47	31.70	1.03
TPT Total Time	1.18[1,2]	1.14	0.69[1]	0.38	0.67[2]	0.42	3.69[a]
TPT Memory	6.77	2.31	7.82	1.33	7.79	1.37	2.22
TPT Localization	2.77	2.16	3.14	1.88	3.45	2.63	0.47
Seashore Rhythm	22.93[1,2]	3.07	24.52[1]	3.53	25.17[2]	2.79	4.33[a]
Speech Perception	11.00	7.95	8.17	5.71	7.93	5.77	2.85
Finger Tapping	43.39	8.64	44.66	7.72	46.63	5.99	0.95
Impairment Index	0.70[1,2]	0.24	0.57[1]	0.23	0.48[2]	0.28	4.98[b]
Trail Making, Part A	49.74[1]	37.00	44.28[2]	42.33	30.07[1,2]	11.07	4.44[a]
Trail Making, Part B	149.00[1]	103.64	112.79	70.27	91.67[1]	42.62	3.31[a]
WAIS Verbal IQ	96.45	15.71	102.00	14.46	103.50	14.91	2.03
WAIS Performance IQ	89.61	13.00	94.52	12.70	96.20	13.23	2.49
WAIS Full Scale IQ	93.19	14.21	98.76	12.73	100.47	14.02	2.33
Perceptual Errors	20.13[1,2]	17.31	13.76[1]	18.52	11.67[2]	12.26	4.06[a]
Dynamometer	38.50[1]	14.05	47.47[1]	12.18	43.47	12.11	3.18[a]

[a] $p < 0.05$, $F \geqslant 3.11$.
[b] $p < 0.01$, $F \geqslant 4.86$.
Note: All F statistics were calculated on the basis of data in T score form. Identical single numerical superscripts within each test variable indicate significant differences of $p < 0.05$; if underlined, of $p < 0.01$.

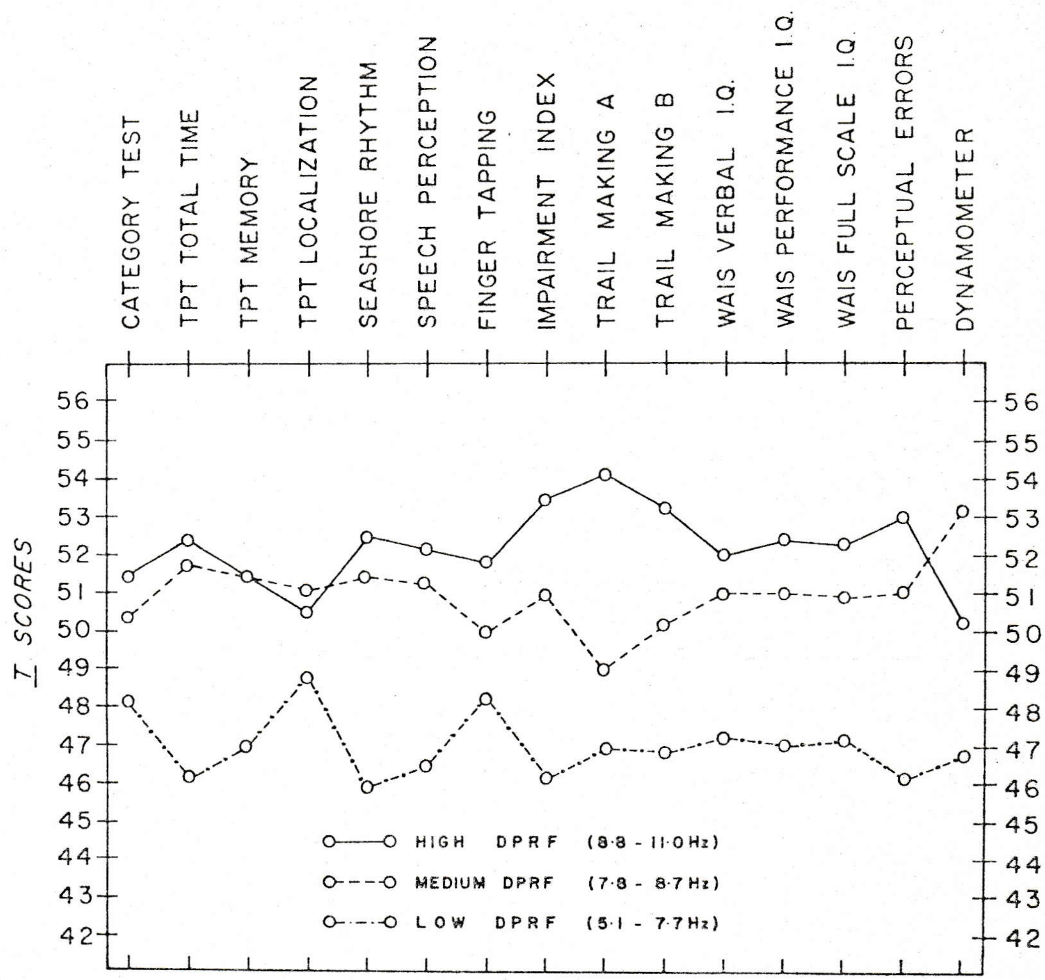

FIG. 1. Neuropsychological performances of patients grouped according to dominant posterior rhythm frequency (DPRF).

manipulation, and whereas the questions are often difficult, they are not always complex. Also, the tasks do not necessarily require sustained attention. The Performance subtests of the WAIS, however, involve a moderate amount of both attention and complex mental manipulation. Thus, studies relating DPRF with intelligence may be expected to vary in outcome depending in part upon the structure of the tests used to assess intelligence, and one possible explanation for the divergent findings of previous investigators (e.g., Shagass, 1946; Giannitrapani, 1969) is apparent.

Choice of statistical methods could also account for some of the differences in results between our analyses and their variation from the findings of previous investigators. For example, in our study, a greater number of significant differences were obtained when the patients were divided into three instead of into two equal groups, and it was observed that the former analysis permitted persons with rhythms below about 8 Hz to be separated from the rest. With respect to other investigators, Giannitrapani (1969) used correlation coefficients to describe relationships between the WAIS and EEG rhythms with many positive findings. Had we used this approach, correlations between DPRF and WAIS Verbal (0.26), Performance (0.31), and Full Scale (0.30) IQs in our study would have been uniformly statistically significant ($p < 0.02$). Using procedures designed to

TABLE 2. *Means, standard deviations, and* F *statistics from two-way analysis of variance procedures with patients grouped according to DPRF (low = 5.5-8.2 Hz; high = 8.3-11.0 Hz) and presence and absence of EEG epileptiform discharges (ED present, ED absent)*

Test variable	Groups: DPRF Low ED Present Mean	SD	DPRF High ED Present Mean	SD	DPRF Low ED Absent Mean	SD	DPRF High ED Absent Mean	SD	F statistics: Main effects DPRF	ED	Interaction effect
Category Test	66.48	33.44	58.97	28.21	56.94	31.03	44.31	26.07	2.08	5.17[a]	0.38
TPT Total Time	1.23	1.18	0.76	0.43	0.64	0.37	0.54	0.20	1.84	11.30[b]	0.56
TPT Memory	6.55	2.20	7.39	1.32	8.19	1.52	8.40	1.18	1.31	14.26[c]	0.38
TPT Localization	2.41	1.68	2.82	1.96	4.00	2.68	4.13	2.62	0.16	8.20[b]	0.07
Seashore Rhythm	23.43	3.62	24.69	2.63	22.81	2.95	26.00	3.01	10.25[b]	1.05	2.27
Speech Perception	10.62	9.16	8.41	5.69	9.88	5.07	6.56	2.90	3.67	0.12	0.69
Finger Tapping	41.83	9.32	46.24	6.71	47.00	5.59	46.06	6.21	0.80	2.13	1.87
Impairment Index	0.68	0.26	0.57	0.27	0.56	0.26	0.47	0.25	2.93	5.39[a]	0.03
Trail Making, Part A	57.86	51.98	35.90	16.29	34.44	17.54	29.69	10.73	3.10	5.70[a]	0.40
Trail Making, Part B	158.07	108.39	109.90	55.91	102.81	58.35	78.00	33.92	4.67[a]	8.19[b]	0.01
WAIS Verbal IQ	96.86	16.92	98.41	13.91	102.31	12.58	109.69	13.87	2.39	6.37[a]	1.10
WAIS Performance IQ	86.24	12.69	92.62	12.35	97.38	9.78	103.19	10.83	6.62[a]	18.23[c]	0.00
WAIS Full Scale IQ	91.93	14.85	95.76	12.93	100.38	10.98	107.25	11.05	3.73	11.34[b]	0.52
Perceptual Errors	22.00	17.66	12.31	12.43	10.31	8.55	13.31	23.05	3.09	5.37[a]	4.21[a]
Dynamometer	41.15	14.99	44.86	12.79	44.12	13.64	42.31	10.34	0.02	0.01	1.14

[a] $p < 0.05$, $F \geq 3.96$.
[b] $p < 0.01$, $F \geq 6.96$.
[c] $p < 0.001$, $F \geq 11.74$.
Note: All F statistics were computed on the basis of data in T score form.

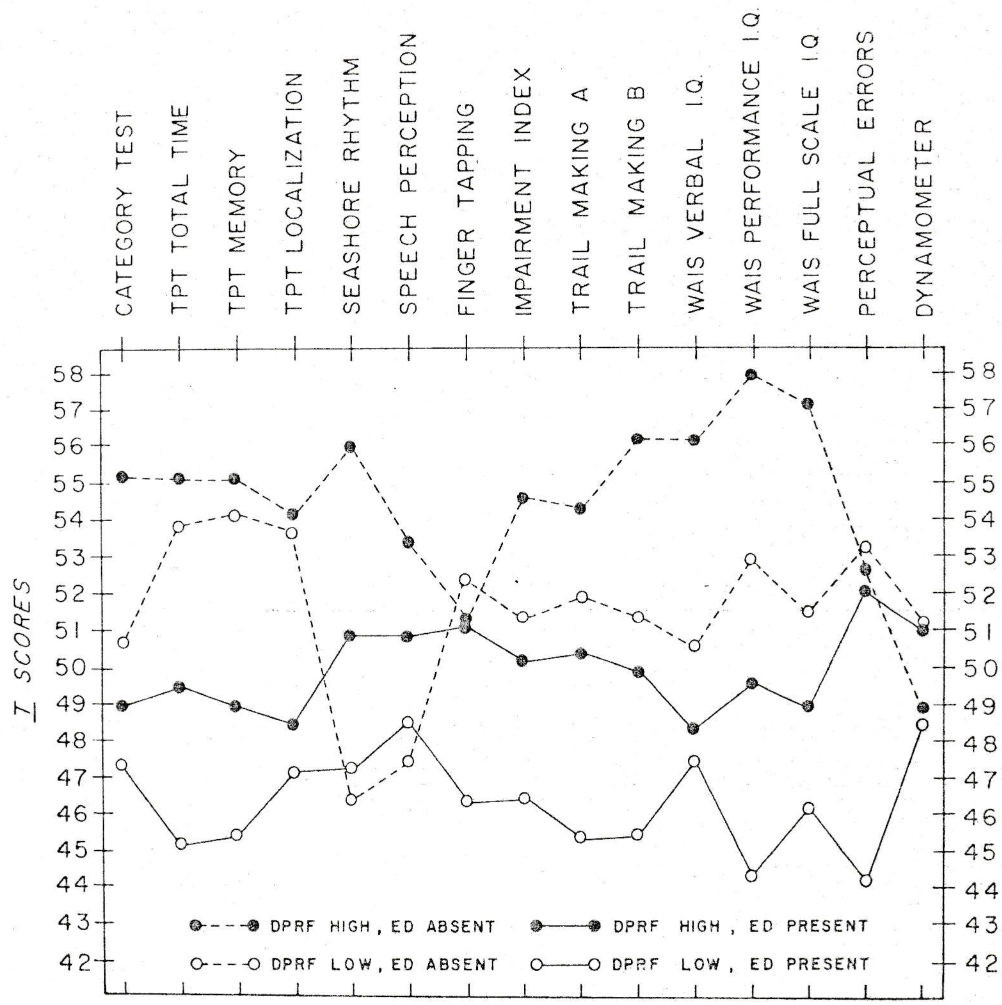

FIG. 2. Neuropsychological performances of patients grouped according to dominant posterior rhythm frequency (DPRF) and presence or absence of epileptiform discharges (ED).

detect actual differences between groups instead of general relationships, however, we were not usually able to arrive at statistically significant probabilities with intellectual variables.

The wide range of rhythms assessed by us could help to explain the contrast of our findings to those reported by some other authors. For example, we found that most correlations between neuropsychological abilities and DPRF occurred below 8 Hz, with only very modest improvements in abilities as DPRF further increased. This probably accounts for the negative results of previous investigators who limited the scope of their analyses to the study of patients with EEG rhythms of 8 Hz or faster (e.g., Shagass, 1946; Mundy-Castle, 1958; Saunders, 1961).

The presence or absence of ED was a more potent variable than DPRF when they were simultaneously evaluated. However, unique variations in test scores due to joint interactions of ED and DPRF were not found. Nevertheless, the simultaneous consideration of these variables resulted in a clear ordering of means with a greater dispersion of scores than when either EEG variable was used alone. Thus, the DPRF High, ED Absent group did best on 12 of 15 test variables, the DPRF Low, ED Absent group did second best on 11, the DPRF High, ED Present group did third best on 12, and the

DPRF Low, ED Present did poorest in 13 instances. We conclude that these EEG variables are additive rather than interactive with respect to the psychological abilities we have chosen to evaluate. As a corollary, we also examined DPRF in relation to rate and topographic distribution of discharges by similar statistical analyses with results which were similar in most respects to those reported here.

Another factor potentially affecting the results is serum drug level. As has been demonstrated (Dodrill, 1975), higher diphenylhydantoin levels are associated with increased neuropsychological impairment. The possibility exists that poorer performance and lower EEG rhythms as presently evaluated could merely be manifestations of this effect. We believe that these factors are related, but would urge caution in drawing conclusions which may eventually prove to be oversimplified. For example, the pattern of impairments associated with diphenylhydantoin therapy (Dodrill, 1975) is different from that seen in this investigation, and the impairments presently noted are definitely broader in scope. Furthermore, the use of EEG variables resulted in a far greater dispersion of psychological test scores than did the use of serum levels alone. As an example, the approximate maximal Full Scale IQ difference between groups in this study was 15 points whereas it was 4 points in a previous investigation (Dodrill, 1975). These factors led us to believe that in this study we were assessing much more than a simple drug effect.

Finally, it should be noted that the EEG evaluations undoubtedly involved some subjectivity and sampling error, even though reasonably good statistical reliability was established for determinations of the DPRF. Furthermore, the neuropsychological tests and EEGs were not performed simultaneously, a fact which likely decreased the probability of obtaining statistically significant findings. One should consider, however, that (1) the reliability of the DPRF measurement as we have performed it is well within the test-retest reliability of the neuropsychological tests themselves (Dodrill and Troupin, 1975), and (2) to the degree that the DPRF and ED measures are error-prone, our studies would more likely *underestimate* rather than overestimate the relationships which might exist.

DPRF appears to be related to those psychological abilities which simultaneously require attention and complex mental manipulations. The assessment of a broad range of skills is essential in order to detect differences which might relate to the DPRF. Similarly, the importance of assessing a broad band of DPRF, including rhythms below 8 Hz, is also apparent. Maximal relationships between psychological and EEG variables occur when more than one EEG variable is examined simultaneously. This study and that by Wilkus and Dodrill (1976) suggest that the greatest impairment in neuropsychological performance is shown when (1) DPRF is less than 8 Hz, (2) ED are present in any amount, and (3) ED are generalized rather than focal. The number of patients was not adequate for these three variables to be studied simultaneously, but we believe that such an investigation would be useful, not only in terms of a multivariate prediction of psychological test results by means of the EEG, but also conceivably in terms of the prediction of EEG findings from psychological test results.

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SUMMARY

Relationships between psychological functions and waking dominant posterior rhythm frequency (DPRF) of the EEG were evaluated with and without simultaneous evaluation of epileptiform discharges. Ninety adult epileptics with uncontrolled seizure disorders treated solely by diphenylhydantoin underwent EEGs during wakefulness and administrations of an extensive battery of neuropsychological tests. The DPRF was particularly related to abilities simultaneously requiring attention and complex mental manipulations. Rhythms slower than 7.5-8.0 Hz were accompanied by relatively poorer performance than rhythms which were faster. When epileptiform discharges were considered in combination with the DPRF, larger differences in abilities were demonstrated, and the psychological correlates tended to be more substantial for the epileptiform discharge variable than for the DPRF variable. The selection of tests employed and the range of rhythms assessed are critical to these findings, and the substantial constriction of these variables by many previous investigators is believed to be related to the negative findings often reported.

RÉSUMÉ

Les relations entre les fonctions psychiques et la fréquence du rythme postérieur dominant de veille (FRPD) de l'EEG ont été évaluées avec et sans évaluation simultanée des décharges de type épileptique. Chez 90 adultes épileptiques avec crises non contrôlées, traitées seulement par la diphénylhydantoïne, des enregistrements EEG ont été pratiqués en même temps qu'une large batterie de tests psychologiques. La FRPD a été mise en corrélation surtout avec les capacités d'attention et d'opérations mentales complexes. Les rythmes inférieurs à 7,5-8 c/s, s'accompagnaient de performances relativement plus faibles que celles obtenues avec des rythmes plus rapides. Quand on considérait aussi les décharges de type épileptique, on trouvait de plus grandes différences et les corrélations psychologiques tendaient à être plus riches pour les variations de décharges épileptiques que pour celles de la FRPD. Le choix des tests utilisés et le spectre des rythmes analysés sont d'une importance capitale et l'on pense que la réduction importante de ces variables dans de nombreuses recherches précédentes explique la fréquente négativité des résultats rapportés.

(C.A. Tassinari, *Marseilles*)

ZUSSAMENFASSUNG

Die Beziehungen zwischen psychologischer Funktion und der Frequenz des dominanten posterioren Rhythmus im Wach-EEG (DPRF) wurden mit und ohne gleichzeitige Berücksichtigung der epileptiformen Entladungen ermittelt. Bei 90 erwachsenen Anfallskranken mit therapieresistenten Anfällen, die nur unter Diphenylhydantoin standen, wurden EEG im Wachen und während der Anwendung einer umfangreichen Batterie neuropsychologischer Tests abgeleitet. Die DPRF hatte besondere Beziehungen zu den Fähigkeiten, die gleichzeitig Aufmerksamkeit und komplexes Denden erforderten. Langsamere Rhythmen als 7,5 bis 8,5 Hz wurden von relativ schwächeren Ergebnissen begleitet als solche mit schnelleren Rhythmen, Betrachtet man die epileptiformen Entladungen kombiniert mit der DPRF, so wurden grössere Unterschiede der Fähigkeiten deutlich und die psychologischen Korrelationen tendierten stärker zu epileptiformen Entladungen als zur DPRF. Die Auswahl der angewandten Tests und die Schwankungen der festgestellten Rhythmen sind für diese Befunde entscheidend. Die substantielle Beschränkung dieser Variablen durch viele früheren Untersucher steht vermutlich in Beziehung zu den häufig berichteten negativen Befunden.

(D. Scheffner, *Heidelberg*)