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Quantitative Electroencephalography (QEEG) and Neuropsychological Syndrome Analysis

B. V. Shenal,[1] R. D. Rhodes,[1] T. M. Moore,[1] D. A. Higgins,[1] and D. W. Harrison[1,2,3]

The ideographic, syndrome analysis and the nomothetic, standardized test battery approaches to neuropsychological assessment are compared and contrasted within the context of advances in noninvasive technology readily available for use within the examiner's office. By demonstrating the relative strengths and benefits of syndrome analysis, it is suggested that this approach provides a thorough and efficient method of neuropsychological assessment. Subsequently, the utility of an a priori hypothesis testing process approach as a critical technique in syndrome analysis will be supported. It will be proposed that QEEG procedures provide a useful method for further substantiating conclusions generated from a syndrome analysis approach to neuropsychological assessment. Two cases are described demonstrating the utility and flexibility of the QEEG as a confirmatory test of localization following syndrome analysis. In summary, the contributions that neuropsychologists make to the understanding of brain–behavior relationships may be strengthened by combining neuropsychological and neurophysiological assessment methods.

KEY WORDS: electroencephalography (EEG); quantitative electroencephalography (QEEG); brain mapping; syndrome analysis; neuropsychological assessment.

NEUROPSYCHOLOGICAL EVALUATIONS

Neuropsychological assessment provides essential information on individuals suspected to have a brain disorder and may be used to localize dysfunctional cerebral regions. Assessment may aid in the understanding and description of an individual's behavioral, affective, and cognitive difficulties, in the prediction of outcome, and in the derivation of effective rehabilitative strategies within a multidisciplinary therapeutic context. As neuropsychological assessment techniques have developed over time, several divergent approaches have emerged. Alternative assessment methods include the hypothesis testing approaches, the process approaches, the Halstead–Reitan approaches, and the Luria–Nebraska approaches (Retzlaff *et al.*, 1992). However, these methods can be grouped within two distinct models: the standardized battery approach and the syndrome analysis approach. These two alternative approaches, including their relative strengths and weaknesses, will be discussed later.

[1]Department of Psychology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24061-0436.

[2]To whom correspondence should be addressed at Department of Psychology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0436.

[3]More comprehensive, anonymous, clinical information is available from this author for both of the presented case studies.

Standardized Battery Approach

Especially within the United States, the standardized test battery has become a common means for neuropsychological assessment. Frequently employed standardized batteries include the Halstead–Reitan Neuropsychological Test Battery (HRNB) and the Luria–Nebraska Test Battery (Iverson *et al.*, 1994). Sellers and Nadle (1992) reported that the HRNB is the most often used formal test battery for all ages. Likewise, Guilmette and Faust (1991) demonstrated that among their respondents 51% of the professionals conducting neuropsychological assessment prefer the HRNB.

Standardized batteries often comprise numerous subtests, which are administered to a representative sample of individuals within a population accounting for age, sex, education, and other demographic variables. Individual

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scores are then compared with these statistical norms to determine relative performance within a "normal" distribution. Atypical deviation from the expected or average score may be used to describe the performance and substantial research is then available to provide a clinically relevant interpretation of the scores.

The strength of the nomothetic test battery approach lies in its ability to identify individuals performing significantly below expectations based on the objective norms established using a large and representative comparison group. Moreover, changes across time may be monitored with repetition of these protocols; yet, these may be confounded by carryover and practice effects (e.g., Shapiro and Harrison, 1990), ambient conditions or context (e.g., Harrison and Kelly, 1989), and a host of psychophysiological variables affected by preexposure and habituation (e.g., Herridge *et al.*, 1997).

A large literature has focused on assessment batteries and the development of improved or more clearly defined statistical test characteristics (Kane, 1991). Researchers continue to explore the usefulness of reducing standardized test battery length, such as the HRNB, to increase clinical utility while preserving psychometric properties (Reeder and Boll, 1992). Currently, however, efforts to meet these goals have been limited. Therefore, the HRNB, as well as other test batteries, requires considerable patient and examiner time, reducing the utility and efficiency of this neuropsychological assessment approach.

Although the benefits of standard test procedures, objectivity, and normative comparisons are well established, this "do it all" approach has several criticisms. First, such tests typically present a tremendous time burden on the individual being tested and the examiner (Kaufman, 1990). Second, patients are often subjected to tests that are not relevant to their presenting problems further contributing to fatigue and assessment inefficiency. Third, standardized test construction is established based on inter-item reliability assessed by redundant test items. The benefits of redundancy may be outweighed by the loss of information from the critical first sample, the potential for confounding practice effects during subsequent items, and the decrease in assessment efficiency (e.g., Summers and Boll, 1987).

In addition to the aforementioned problems, the standardized test battery approach might be criticized for its reliance on measurement theory rather than theory derived from research on brain–behavior relationships. The consequences of this approach should not be underestimated because clinical, research, and training energies may be limited to administration techniques and test validity. Thus, the contribution to developing neuropsychological theory in the broader sense may be minimal. In comparison, the syndrome analysis approach, as discussed later, may contribute more substantially and directly toward understanding functional neural systems and the development or the advancement of neuropsychological theory.

Flexible Approach

Paul Satz (1993) chronicles issues within the context of threshold theory that are especially relevant in cases where nomothetic observations have been made on high functioning individuals. Individuals of high average to superior functioning on standardized tests may demonstrate considerable brain dysfunction yet remain within the average range on the statistical distribution derived from a normative population sample. Accordingly, a nomothetic approach may lower the sensitivity of the testing instruments and support only erroneous conclusions by the clinical observations, as variability within the normal population is substantial. Alternatively, an individual approaching the distribution's lower-end threshold for statistical "abnormality" may already be functioning at a marginal level with a minor loss impacting vocational, social, marital, and emotional integrity. Statistically though, the argument might be made that the degree of loss is minor relative to the normative distribution. Thus, the contributing event (e.g., head injury) would be judged to be insignificant despite the transition from a working member of society to unemployment.

In sharp contrast to the standardized assessment approach, syndrome analysis examines neuropsychological functioning, using a within-subject, a priori hypothesis testing protocol (Luria and Majovski, 1977). The syndrome analysis approach to neuropsychological testing uses a single case design based on a double dissociation approach to the investigation of functional cerebral systems. The patient is subjected to a variety of tasks purported to be sensitive to the functional integrity of the system. The patient is subjected to hypothesis testing of the suspected dysfunctional systems within that individual (Venkatesh *et al.*, 1993). As described by Iverson *et al.*, (1994), varying collections of standardized tests and a hypothesis testing process are used for different presenting problems within the flexible approach.

This approach affords a dynamic, flexible method that focuses on the individual as his or her own control. Therefore, syndrome analysis is a within-subject analysis of brain functioning as compared with the statistical means comparisons of the standardized battery approach. This approach allows the examiner to focus on a syndrome, to generate hypotheses of system dysfunction, and then to systematically test these a priori hypotheses. Moreover, this approach is directed toward the investigation of the organization of mental processes in a single subject.

Further support for a syndrome analysis approach stems from Teuber's principle of double dissociation (see Luria, 1973 for review). This principle states that all functional systems that include a disturbed factor will suffer. Conversely, those functional systems that do not involve a disturbed factor will remain preserved. This principle strengthens the power of hypothesis testing by allowing the examiner to systematically assess multiple subsystems within the central nervous system for dysfunction to differentiate which subsystems are dysfunctional. For instance, McFarland (1983) states that syndrome analysis improves diagnostic decision making and enables probabilities to be associated with particular prognostic statements. Teuber's influential principle of double dissociation is reviewed in the relevant literature (see Weinstein, 1985 for review).

An additional benefit of the syndrome analysis approach is that it allows the clinician to generate meaningful conclusions based on intraindividual functional neural system differences. In other words, the patient under consideration is used as his/her own control because dysfunctional and unimpaired systems are compared with other systems within the individual. This method further allows for the control or investigation of practice effects and learning, which may be confounded with a large standardized test with demonstrated inter-item reliability. Additionally, this approach does not rely on any one system to test another and localizes dysfunction to specific functional systems. Lastly, because this method is not based on the range of abilities, all patients should be able to attempt all tasks within the evaluation.

It is important to consider the relative efficiency of the syndrome analysis approach as compared with the standardized test battery approach. The syndrome analysis approach is frequently completed in a very short period of time. It may be used with patients presenting severe language disorders or aphasias and with patients evidencing altered arousal levels extending to the analysis of a comatose status. HRNB requires a large amount of time, has limited utility with severe aphasia and advanced dementia, and yields scores rather than a useful diagnosis of a clinical syndrome. Further, the efficiency of the syndrome analysis approach minimizes the potential for fatigue, reducing assessment confounds.

Finally, this approach generates research on brain syndromes rather than fostering research on the statistical properties of tests and measurement theory. Although there have been attempts to isolate this approach and label it a "medical approach," syndrome analysis is solidly based in the psychological camp, as it is used to assess behavior and behavioral dynamics. Accordingly, this approach actively contributes to an understanding of brain–behavior relationships and neuropsychological theory.

Psychophysiological Approaches to Neuropsychology

Many techniques used during the growth of the field of clinical neuropsychology have come from past psychophysiological research techniques. These techniques have become less familiar to newer clinicians entering the field of clinical neuropsychology while standardized tests remain well known. Researchers have noted the benefit of including psychophysiological measures when performing neuropsychological assessments. Levine and Gueramy (1991) emphasized that research in the field of psychophysiology contributes directly to a better comprehension of the loss of cerebral functioning due to brain injury. Testing that incorporates psychophysiological measurements in the application of clinical neuropsychology takes advantage of this rich resource, which can also aid in predicting recovery. Further, an effective approach to take when designing neurorehabilitative programs would allow for a complementary integration of neuropsychological rehabilitation techniques with psychophysiological feedback components. Hugdahl (1995) noted that psychophysiology is an important research and clinical tool for assessment, diagnosis, and brain localization in neuropsychology. Often, psychophysiological measures such as electrodermal responding can reveal asymmetrical reactivity across cerebral hemispheres.

Brain imaging techniques can provide invaluable information about both brain structure abnormalities and brain dysfunction that occurs during specific tasks. Physiological imaging techniques such as quantitative electroencephalography (QEEG), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) are some of the more standard approaches to brain imaging. Recent efforts to record EEG and fMRI simultaneously represent an exciting approach to investigating neuronal and regional blood flow changes during mental activity (Knight, 1997). Other psychophysiological techniques (e.g., blood volume pulse amplitude, skin temperature, skin conductance, heart rate, respiration, and surface electromyography) have been used to discriminate brain injured patients from controls, through differing psychophysiological response patterns (Lehrer *et al.*, 1989). Further, imaging techniques, such as QEEG data, collected during auditory and visual focused attention tasks, have been helpful in diagnosing neuropsychological developmental disorders (Lincoln *et al.*, 1998).

Psychophysiological testing is an objective technique, yielding precise data that can be compared over time.

In addition, increased testing through various methodological approaches (e.g., behavioral samples, sensorimotor screening, psychophysiological measures) more reliably indicates cerebral system dysfunction. Consequently, the validity of the testing approach is augmented, while enhancing the clinician's effectiveness. These techniques effectively provide a much needed link between brain and behavior (Gerner, 1981). Pribram (1985) has emphasized that what needs to be shown is that a brain state measured electrically or chemically has the same form as the mental percept.

Lacey (1985) and others have credited Wilhelm Wundt's work, "Principles of Physiological Psychology," published in 1874, as one of the principal events in psychophysiological theory development. Later, through Lashley's initial ideas and more recent research, the hybrid discipline now known as neuropsychology was advanced. Sidney Weinstein (1985) has eloquently recounted some of the first research conducted in the field of neuropsychology, with certain origins in psychophysiological research. He mentioned the first attempts to differentiate between right and left hemispheric functioning, the study of sensory perception from a cerebral perspective, and seminal research conducted in the field of neuropsychology following traditional psychophysiological research protocols. Veterans of World War II allowed Weinstein and his fellow researchers at the Psychophysiological Laboratory of New York University to study neurological patients injured during conflict, often enabling more precise localization of function than had been discovered by past research. Their work, and research conducted concurrently at other labs (e.g., Hebb, 1959; Luria, 1962/1966; R. W. Sperry, as cited in Puente, 1995), has contributed greatly to the understanding of brain–behavior relationships, the basis of current neuropsychological theory.

QEEG Analysis

As syndrome analysis has developed into a common approach for neuropsychological assessment, additional methods of data quantification have been developed and utilized. Boll (1977) posed that "by establishing a connection between neurological criteria and human behavior, the base for developing an understanding of brain–behavior relationships is provided" (p. 64). With advances in brain imaging technology, such relationships can be established and quantified. Brain scan techniques such as computerized tomography (CT) have been shown to produce useful models for predicting the neuropsychological outcome of brain injured patients (Turkheimer *et al.*, 1990). For example, Fowler *et al.*, (1987) demonstrated that specific deficits were related to left and right hemispheric dysfunction as measured by electroencephalogram (EEG) analysis. Additionally, quantitative electroencephalogram (QEEG) and topographical brain mapping have been successful in demonstrating localization and verification in studies concerning right and left cerebral hemispheric dysfunction (Demaree *et al.*, 1995; Duffy, 1994; Everhart and Harrison, 1995).

QEEG Controversies

The initial EEG work of Hans Berger, a German clinical neuropsychiatrist who was the first to record the electrical activity of the human brain, was widely disregarded and almost entirely unconvincing. With perseverance and replication by other individuals, however, the EEG has become a widely accepted neurological technique. As with the initial controversy with EEG, there currently exists a significant and legitimate scientific debate concerning the clinical utility of the QEEG. Following a review of the QEEG literature, Nuwer (1997) stated a number of problems and controversies regarding the clinical role of QEEG analysis techniques. These issues are presented in an American Academy of Neurology and American Clinical Neurophysiology Society special article report (Nuwer, 1997). Included in this position statement is the comment that "EEG brain mapping and other advanced QEEG techniques should be used only by physicians highly skilled in clinical EEG, and only as an adjunct to and in conjunction with traditional EEG interpretation" (p. 282). This position is based on several criticisms of QEEG techniques.

First, Nuwer (1997) argued that QEEG techniques often vary between laboratories and technical differences may interfere with clinical utility. Second, the data-processing algorithms may produce unusual and surprising artifacts (Nuwer, 1997). Third, abnormal EEG activity could potentially be overlooked or misinterpreted with QEEG analysis alone. Fourth, Nuwer (1997) stated that the clinical utility of the QEEG is further compromised by patients who receive certain medications and that drowsiness can mimic disease on the QEEG record. Fifth, evaluation of QEEG analyses has not yet demonstrated its utility in providing clinical differential diagnoses. Finally, Nuwer (1997) argued that QEEG techniques are predisposed to false-positive errors as a result of these problems combined with the possibility of chance abnormalities following a large battery of QEEG tests.

Rebuttals to Nuwer's (1997) concerns and the American Academy of Neurology and American Clinical Neurophysiology Society position statement regarding

QEEG techniques have recently been presented. These rebuttals specifically address the reported controversies (see Hoffman *et al.*, 1999; Thatcher *et al.*, 1999, for review). Furthermore, a prior review of QEEG by Duffy *et al.* (1994) provided specific recommendations for many of the problems reported by Nuwer (1997). Additional clinical replications and continued scientific investigations are clearly needed to provide empirical support for the utility of the QEEG.

QEEG and Neuropsychology

Although there has been notable controversy regarding the acceptance of QEEG, the majority of arguments against the clinical utility of QEEG have been presented in position papers lacking quantifiable data. Currently, the application of QEEG has not been clearly adopted within the fields of neurology, psychiatry, or psychology. The field of neuropsychology affords the unique strength of combining an understanding of brain–behavior relationships with scientific, experimental expertise. Accordingly, neuropsychologists may provide an appropriate combination of scientific and clinical abilities to promote the continued task of experimentally investigating QEEG utility.

Nomothetic Basis

Thatcher *et al.* (1991) demonstrated that QEEG may be useful within a nomothetic context where measurement theory is used to predict the magnitude or power values for given EEG bandwidths at specific electrode sights (e.g., the 10–20 system). Although beyond the scope of this review of QEEG utility, database sets are currently available for nomothetic comparisons and provide a useful method of interpreting QEEG data. Thatcher (1998) suggested that QEEG databases will play an increasingly important role in the patient evaluation. Presently, there are few QEEG reference databases that adequately meet the standards necessary for ethical and responsible QEEG uses. The Thatcher normative EEG database is the prominent reference database throughout the QEEG literature (Thatcher, 1998). Additionally, a recent chapter by Thatcher (1999) presents a broad range of QEEG database issues. This review is especially useful for clinical applications of QEEG. A "reference" normative QEEG database is discussed along with a review of the utility of clinical QEEG biofeedback and neurotherapy. Specific criteria for the use of a reference normative QEEG database are also presented (see Thatcher, 1999, for review).

Ideographic Basis

Although nomothetic comparisons of QEEG data may be informative, the strength of QEEG as a measurement tool is further established by utilizing an ideographic basis to make within-patient comparisons across homotypic brain regions (e.g., left frontal leads F1, F3, and F7, with right frontal leads F2, F4, and F8, respectively). This within-patient comparison follows well from syndrome analysis instead of nomothetic observations (Moore *et al.*, 1999). Nesting the QEEG within a syndrome analysis approach based on Teuber's principle of double dissociation may provide a powerful and objective basis for investigating a priori hypotheses for cerebral dysfunction identified from the neuropsychological evaluation. Thus, QEEG and syndrome analysis approaches facilitate an understanding of brain mechanisms involved beyond that derived from a nomothetic criterion and measurement theory. In addition, the relationship between functional activity may be better understood within a functional systems perspective with overactivation and underactivation of EEG bandwidths contributing to the syndrome identified. The use of QEEG analysis in continuity with the syndrome analysis is beneficial as it provides additional and objective verification or disconfirmation of hypothesized regional cerebral dysfunction. This may strengthen the clinical utility of the neuropsychological evaluation within diagnostic, prognostic, and forensic settings.

QEEG Methods and Definitions

QEEG evaluations are performed following a standardized protocol but are amenable to single subject experimental manipulations. The QEEG should be performed after the completion and interpretation of the neuropsychological assessment to serve as a confirmatory test of the assessment predictions. The evaluation protocol calls for the patient to be relaxed, but awake, with eyes closed. While data are recorded from 19 scalp locations, the patient is requested to keep his/her eyes closed and remain motionless in a near supine position on a reclining chair. Electrode placement occurs via a lycra electrode cap, designed to match the standardized 10–20 system of EEG recording (see Fig. 1). Epochs containing eye-blinks or muscle movement artifact or both of these are excluded from the resulting analysis. All remaining data are assessed using the Neurosearch-24 (Lexicor Medical Technology, 1992).

The scalp-recorded EEG is generated by the pooled activity of the cortical neurons that is influenced by shared activity between cortical and subcortical regions (Cantor,

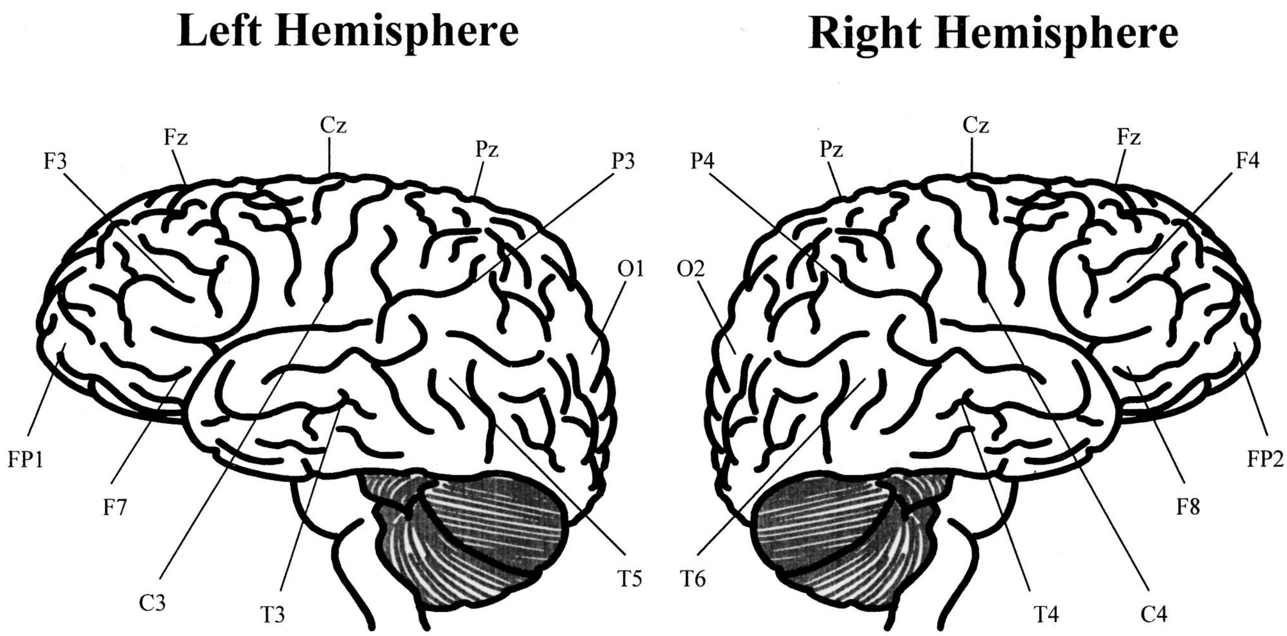

Fig. 1. QEEG electrode sites (10/20 system).

1999). Additionally, each electrode site records EEG activity from multiple rhythmic generators. There are two types of EEG montages that are commonly used. The referential montages (monopolar) compare activity at the active site with activity from a common reference electrode. Reference electrodes, such as the earlobes, are relatively unaffected by cerebral activity (Cantor, 1999). The primary advantage of referential montages is that the common reference provides a method to compare activity across many different electrode pairings. However, because referential electrode sites may pick up minute EEG activity, no reference site is ideal (Cantor, 1999). Bipolar montages subtract the shared activity form two electrode sites, so that only the difference in activity is shown (Cantor, 1999). A benefit of this method is that electrophysiological localization is somewhat easier. However, this method results in a loss of useful information as only differences are shown.

Assessment of EEG activity is typically presented as *coherence*, *symmetry*, and *spectral power*. Coherence is a measure of synchronization between activity in multiple channels. *Coherence* analyses afford a useful method of comparison potentially somewhat unaffected by variations in arousal and mood states. This method of analysis was used to support a QEEG model of coherence in which different features of coherence are produced by different length fiber systems (Thatcher *et al.*, 1986). *Symmetry* analyses present the data as a ratio of power in each band between a symmetrical pair of electrodes. This ratio provides direct multiple-electrode comparisons. The *spectral power* measure (μV^2/Hz) combines amplitude with frequency to indicate the overall energy of a waveform within a particular frequency band (see Moore *et al.*, 1999, for review). Frequency bands are measured in Hertz (Hz) and typically range from 1–30 Hz. Further, these frequency bands correspond to specific mental states or arousal levels. Delta waves correspond to 0.5–4 Hz and are found during deep sleep in normal individuals. Accordingly, delta waves are frequently observed when an individual is in a deep stage of sleep. Theta waves (4–7 Hz) are associated with drowsiness and are frequently observed during light sleep stages. Alpha waves (8–12 Hz) are associated with relaxed, but awake states and Beta waves (13–30 Hz) are fast, irregular waveforms associated with heightened arousal. Beta waves are typically increased in the QEEG record of an individual who is awake and alert. Amplitude, measured as voltage, is measured from the peak of one wave to the trough of the following wave (Cantor, 1999). Stimulation typically attenuates EEG amplitude and minimal EEG activity within a frequency band is termed *suppression*.

The aforementioned brainwaves and related behavioral states reflect activation patterns within "normal" individuals. Accordingly, QEEG records that identify brainwave activation patterns inconsistent with these established behavioral norms may provide a useful indicant of cerebral dysfunction. For example, an individual demonstrating increased delta magnitude localized at the temporal lobe during an auditory task may indicate dysfunction within this region.

Cantor (1999) described QEEG morphology as the "shape" of the QEEG signals. Terms such as *transient*, *spike*, and *complex* are used to describe signal morphology. A transient is an isolated feature that is contrasted by the background activity. A very brief peak in waveform, less than 70 ms, is called a spike. The term complex indicated that multiple waves co-occur and consistently repeat with one another.

QEEG Applications

Three distinct, yet valid applications to understanding cerebral dysfunction and brain–behavior relationships are afforded through QEEG analyses. First, QEEG analyses may reveal important interhemispheric comparisons in patients with suspected cerebral dysfunction. For example, the QEEG analysis of an individual with left hemisphere damage would be expected to reveal impaired activation patterns for the left (but not the right) hemisphere. The QEEG may be used to verify a localized diagnostic impression following a syndrome analysis assessment. Specifically, as the syndrome analysis is a hypothesis-driven assessment approach, the QEEG evaluation is performed as a confirmatory test of the assessment results, with a priori predictions made from the previous neuropsychological examination. The resultant QEEG data either provide support or refute the findings of the neuropsychological examination.

Second, the QEEG data allow statistical analyses of multiple point comparisons of various electrode sites within a single individual. Therefore, the QEEG affords a statistical method of analysis comparing the digital value of a specific site with all other sites. For example, a neuropsychological evaluation utilizing syndrome analysis of a patient with Wernicke's aphasia should identify difficulties in verbal reception. QEEG analyses could serve to verify such findings by demonstrating a statistically reliable discrepancy between activation over Wernicke's area versus activation in areas not associated with verbal reception. Accordingly, QEEG analyses allow for the examination of each patient serving as his or her own control, therefore improving the sensitivity with which an individual's unique cerebral functioning is examined.

Third, the QEEG analysis allows the examiner to investigate cerebral functioning during different affective and cognitive states. The examiner may experimentally manipulate cognitive or emotional conditions to systematically test cerebral activation patterns during these conditions. QEEG recording while a patient is in a specific affective state or during a specific cognitive task may provide additional diagnostic information and useful documentation.

SUPPORTIVE CASES

Two supportive cases are presented to demonstrate the efficiency and utility of hypothesis generation and testing through syndrome analysis with the inclusion of the QEEG. The first case describes an individual with speech and language deficits consistent with an aphasic disorder. The second case describes a patient with generalized cognitive dysfunction. Each case includes a description of the dysfunctional processes, a summary of neuropsychological assessment data, and further evaluation/confirmation of the syndrome analysis using the QEEG. Additionally, each case will highlight a separate method for analyzing the QEEG data. Analyses include an interhemispheric comparison (left versus right) and a within-subject statistical approach.

Interhemispheric Comparison

History

The patient was a 54-year-old, white, right-handed female, referred for neuropsychological evaluation and syndrome analysis. According to self-report and medical records, she suffered mild to moderate head trauma secondary to a fall as a result of an altercation approximately 6 years earlier. Following the accident she maintained consciousness, but recalled feeling dazed and reported difficulty in walking.

The patient reported numerous complaints subsequent to the injury, including short-term memory deficits, intermittent double vision, chronic sinusitis, weight gain, hip pain, and decreased enjoyment for the taste or flavor of foods. Additionally, a previous neuropsychological evaluation indicated word-finding deficits, delayed reaction times, planning deficits, affective disregulation, chronic neck and low back pain, depression, and posttraumatic stress disorder.

Prior to this injury, the patient was employed as a psychiatric nurse for 28 years. She has a history of migraine headaches and experienced an episode of major depression in 1986, resulting in temporary hospitalization. She reportedly received outpatient psychotherapy for several years following hospitalization without the need for psychotropic medications.

Neuropsychological Assessment

The speech evaluation was positive for perseverative features in both repetition testing and conversational output. Confrontational output was tested to be positive for anomia as well as impaired verbal fluency, using the Controlled Oral Word Association Test. Performance on this test yielded a mean of 10 words generated across three 1-min samples using letters F, A, and S. This places her at approximately the 22nd percentile for verbal fluency, well below what was expected given her educational and occupational background. Speech was also noted to be hoarse and of low volume. Patient complained of allergies, but reported that the onset of her soft, hoarse, whispered speech co-occurred with her head injury.

Motor performance assessment was positive for right hemibody impairments. The Dynamometer Grip Strength, Perseveration, and Fatigue test yielded evidence for right hemibody difficulties on two procedures. Full strength grip was 28 kg for the left hand, whereas only 23 kg for the right hand. Thus, she failed to show the right hand superiority for grip strength that would be expected in a right-handed individual. Additionally, the fatigue testing was positive for increased fatigue at the right hand, in comparison to the left hand. Like the full grip strength procedure, these results are opposite to what would be expected in an individual expressing a right hand preference. Relatedly, inspection of the patient's shoe tread wear pattern revealed increased wear of the left sole, indicating a leftward shift of weight bearing during ambulation. Rapid alternating movements were essentially normal, but there was more difficulty with movements of the right hand. Parietal drift test was positive for upward and mesial drift of the right arm. Testing for behavioral slowing with the Trail Making Test was impaired on both parts—A and B.

Spatial awareness screening was functional for all procedures. There was, however, some delay and uncertainty on testing for left/right awareness, indicating that while functional, this is problematic for her. She also displayed a consistent leftward shift during the Complex Figure Copying and Recall tests (Rey Figure), possibly suggesting a mild right hemineglect.

Standardized testing with the Denman Neuropsychology Memory Scale indicated deficiencies within the Verbal Memory Subtests that were not apparent in the Nonverbal Memory scores. Verbal scaled scores ranged from impaired to average, whereas Nonverbal scaled scores ranged from average to superior. Comparison of her Verbal (92) and Nonverbal (103) Memory Quotients showed a statistically significant difference ($p < .005$). Specifically, her Verbal Memory Quotient was significantly lower than her Nonverbal Memory Quotient.

In sum, the results from the neuropsychological assessment are suggestive of primarily left frontotemporal cerebral dysfunction. This interpretation is supported by the following: impaired verbal fluency to confrontation; behavioral slowing; deficits on dual or multiple task requirements; relative deficits in verbal memory as compared with nonverbal memory measures; relative weakness at the right upper extremity; increased fatigue at the right hand in comparison to the left; evidence of increased weight bearing at the left lower extremity; mild upward and mesial drift of the right arm; and expressive speech problems or expressive dysphasia with anomia.

QEEG Evaluation

The QEEG was performed with the a priori expectations of left frontal and left frontotemporal dysfunction. Analysis focused mainly upon the magnitude (μV) of high Delta (2–4 Hz). Delta was chosen for the analysis, as it has been most frequently associated with dysfunction in awake individuals. Heightened Delta magnitude across homotypic comparisons was interpreted as support for dysfunction of that region.

Results of the QEEG were supportive of the a priori predictions made from the neuropsychological evaluation. Delta magnitude was consistently higher for the left hemisphere sites, in comparison to homologous sites at the right hemisphere. Specifically, left frontal and frontotemporal sites were significantly lower than the analogous sites in the right hemisphere (see Figs. 2 and 3). Individual analysis of sites yielded substantial differences between the frontal poles, with the left (FP1) showing greater magnitude of Delta than the right (FP2), 16.1 and 8.1 μV, respectively. Other frontal sites (F7 & F3 on the left, and F8 & F4 on the right) showed the same increase in Delta magnitude, 11.4 and 12.6 μV for the left hemisphere sites as compared with 7.7 and 11.4 μV for the right hemisphere sites. This increased Delta activation is also seen in the left temporal lobe, as predicted by the neuropsychological evaluation. Left temporal leads (T3 & T5) show increased levels of Delta magnitude as compared with the right temporal leads (T4 & T6). Delta values are 8.2 and 13.5 μV on the left, as compared with 7.5 and 11.4 μV on the right.

A finding that was not predicted by the neuropsychological examination, was an increase in Beta magnitude at the right occipitut. There were no indicators for this from the previous evaluation. Although unexpected, this finding

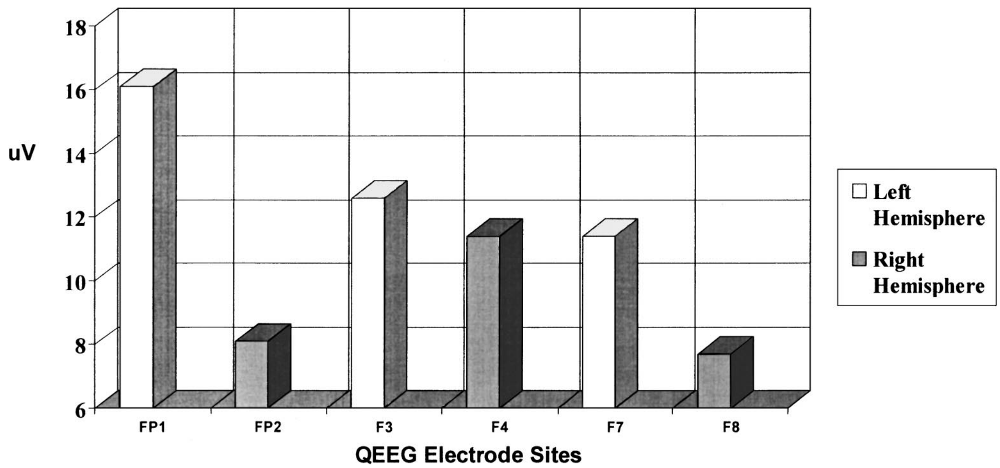

Fig. 2. Delta magnitudes (μV) for left and right frontal regions.

would potentially be consistent with a coup/contracoup injury from the blow she suffered to the head. Even though this was not an expected finding, it was informative and suggests that the patient should be monitored for visual and visual-spatial impairments.

Integration of Syndrome Analysis and QEEG

This patient was pursued for neuropsychological assessment through the use of a syndrome analysis approach. Findings from this exam were interpreted as being most indicative of left hemisphere dysfunction specifically at the frontal/frontotemporal region. Consistent with the hypothesis-driven nature of the neuropsychological assessment, the QEEG evaluation was performed as a confirmatory test of this assessment, with a priori predictions made from the previous examination. The results from the QEEG served as support for the neuropsychological evaluation, with the electrophysiological recordings indicating hypoactivation (dysfunction) in the left frontal and frontotemporal regions.

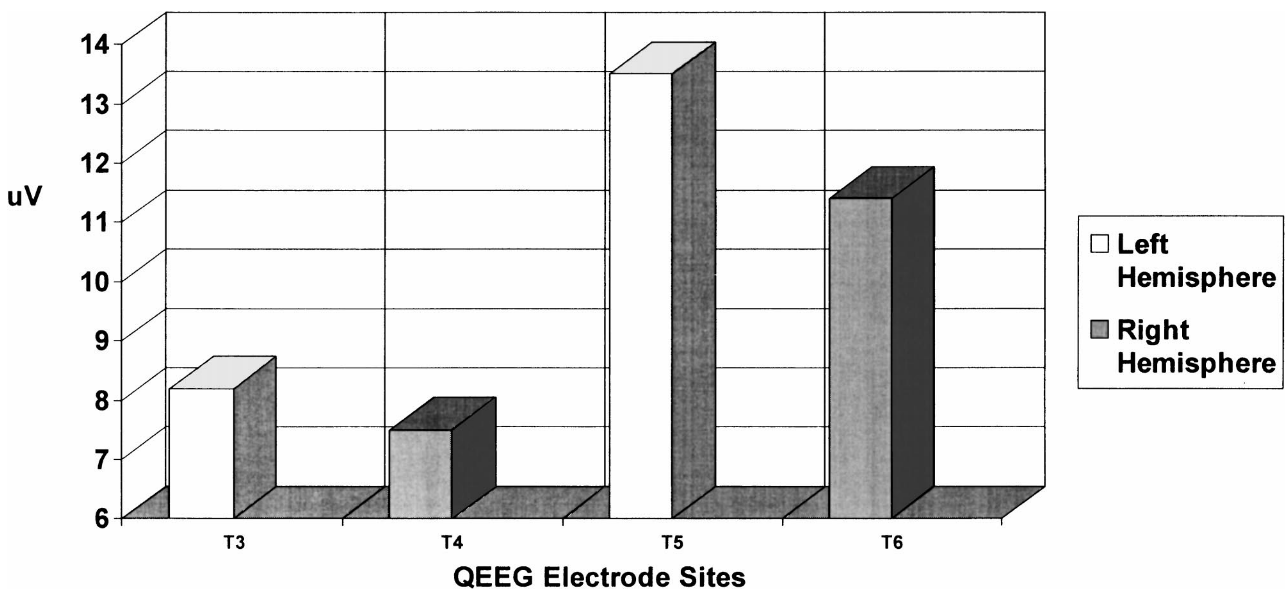

Fig. 3. Delta magnitudes (μV) for left and right temporal regions.

Within-Subject Statistical Analysis

History

The patient was a 29-year-old, white, left-handed male. He was referred for evaluation and quantification of deficits due to an automobile accident 4 years earlier. Medical records noted chronic pain syndrome and residual deficits in cognition, memory, and personality consistent with mild traumatic brain injury. Self-report and follow-up evaluations noted a decline in status between the accident and neuropsychological assessment.

The patient reported multiple concerns, including numbness at his hands, sleep onset and maintenance difficulties, weight loss, apprehension for movement within his peripheral visual fields, difficulty with memory, frustration and anger, and chronic pain at multiple locations. He reported being socially avoidant and depressed. Testing performed 1 year after the automobile accident identified impairments in "visual memory" and "attention/concentration." Verbal memory was reported to be normal (102), whereas his IQ scores were in the Borderline range (Verbal = 78, Performance = 71, and Full Scale = 74).

Neuropsychological Assessment

Affective screening was positive for impression of socially avoidant and withdrawal behaviors. Screening was also positive for impaired management of anger and frustration. Affective interview revealed significant adjustment issues with respect to his disabilities. Social presentation was generally pleasant, but with features of both anxiety and depression.

Motor exam was confounded by peripheral injuries and multiple bracing supports. Physical supports included a support sling at the right arm, clavicle brace at the right shoulder, rib belt, back brace, leg brace at the right, and foot orthotics bilaterally. The majority of the motor assessment procedures were negatively impacted, or halted, secondary to pain complaints. Results indicated impairments at both left and right hemibody. The motor exam was remarkable for pronounced notching and resting tremor of the mandible.

Assessment of fluency for both verbal and nonverbal measures revealed performances in the impaired range. Specifically, he was able to generate a mean of only 6.7 words per minute across three separate letter (F, A, and S) trials. Similarly, on the Ruff Figural Fluency Test, he scored in the low average range for number of unique designs produced. Comparing number of perseverative designs to number of unique designs was positive for impaired functioning.

Spatial awareness screening resulted in mixed findings, with impairments in Gestalt closure tasks (i.e., Luria cards), recognition of number orientation, and also recognition of letter orientation. Geographical awareness, however, was accurate. The Rey Complex Figure Copy Test was positive for moderate to severe visual-spatial deficits, confirming the impression of constructional dyspraxia.

Sensory screening revealed similarly mixed findings. Visual fields appeared somewhat restricted at the right, suggestive of an incomplete right hemianopsia. Lateral gaze testing yielded nonparallel eye movements and diplopia bilaterally. Visual smooth pursuit was quite effortful, yielding high-frequency tremor of the eyelids and nonconjugate gaze. Auditory assessment was essentially normal. Tactile assessment was remarkable for decreased sensitivity at the right, as well as extinction of the right on dual concurrent stimulation.

Memory assessment was indicative of moderate to severe impairments in learning and memory. Testing with the Rey Auditory Verbal Learning Test resulted in only six words being acquired by the end of the fifth trial. Additionally, performance revealed a marked recency effect on the test. Subtests from the Denman Neuropsychology Memory Scale were consistent with severe impairment for both Verbal and Nonverbal tests. Scaled Scores ranged from 1 to 4, with a Scaled Score of 10 being average for the patient's age group. These results are consistent with the complaints of decline in functional status, as testing 3 years earlier indicated verbal memory ability to be in the normal range.

In sum, this evaluation was positive for sensory, motor, speech, memory, and organizational deficits consistent with generalized cerebral dysfunction. Results were suggestive of relative impairment for the basal and subcortical anterior cerebrum extending to the temporal region.

QEEG Evaluation

The QEEG evaluation was performed with the prediction of generalized cerebral dysfunction, but with an area of increased activation for the right frontal lobe (based on the incomplete right hemineglect syndrome). The record was confounded by EMG because of the resting tremor of the patient's jaw. Postural changes helped to alleviate much of this confound, and 198 epochs were recorded for the eyes-closed relaxed condition. Of the 198 epochs recorded, 49 were left for analysis after artifact elimination procedures were performed. Analysis focused

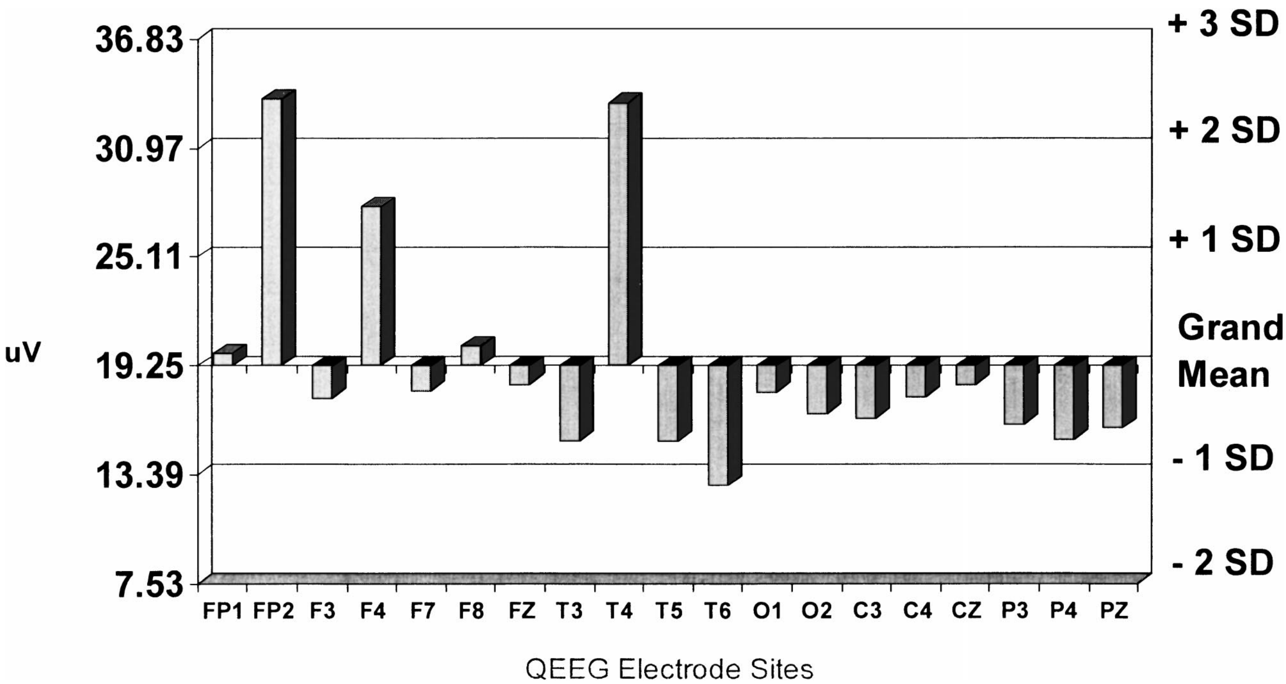

Fig. 4. Standard deviations for individual beta magnitudes (μV) derived from grand mean magnitude.

mainly upon the bandwidths of High Delta (2–4 Hz) and Beta (13–25 Hz).

Comparing each individual electrode site against all other sites revealed relative activation at the right frontal and temporal regions. More specifically, focal Beta activation was observed at both right frontal and right temporal electrode locations. Statistical analysis confirmed significant activation at the right frontal pole. Beta activation for FP2 (33.5 μV; mean $= 19.25$, $SD = 5.86$) was two standard deviations above the mean in comparison with all other electrode sites. Similarly, Beta activation at the right temporal region (T4) was also two standard deviations above the mean (33.4 μV; mean $= 19.25$, $SD = 5.86$). Additionally, Beta activation at the right frontal site F4 was one standard deviation above the mean (27.8 μV; mean $= 19.25$, $SD = 5.86$; (see Fig. 4).

Comparison of electrode sites for Delta magnitudes revealed multiple areas of hypoactivation across the frontal and temporal regions, bilaterally. Increased Delta magnitudes were seen at the right frontal pole FP2 (12.8 μV; mean $= 9.75$, $SD = 1.39$), at the left frontal pole FP1 (11.7 μV; mean $= 9.75$, $SD = 1.39$), and at the right frontal site F8 (12.2 μV; mean $= 9.75$, $SD = 1.39$). Aberrant Delta values were also seen at bilateral temporal regions (see Fig. 5).

Thus, the QEEG was consistent with the predictions made from the neuropsychological evaluation, with increased right frontal activation and generalized areas of hypoactivation bilaterally. Given the patient's impaired performance, localization was difficult. However, using the patient as his own control group allowed for comparisons to be made across all electrode sites and identify areas of dysfunction. With these data, it would then be possible to implement further testing focused on specific areas to further elucidate his deficits.

Integration of Syndrome Analysis and QEEG

The neuropsychological evaluation was indicative of diffuse cerebral deficits, with the suggestion of increased right frontal activation. The QEEG evaluation supported these predictions. There was increased activation at the right frontal pole, while there were areas of abnormal Delta activation across both hemispheres.

Conclusions

In conclusion, the flexible syndrome analysis approach to neuropsychological assessment offers an examiner many strengths and utilities. First, this approach

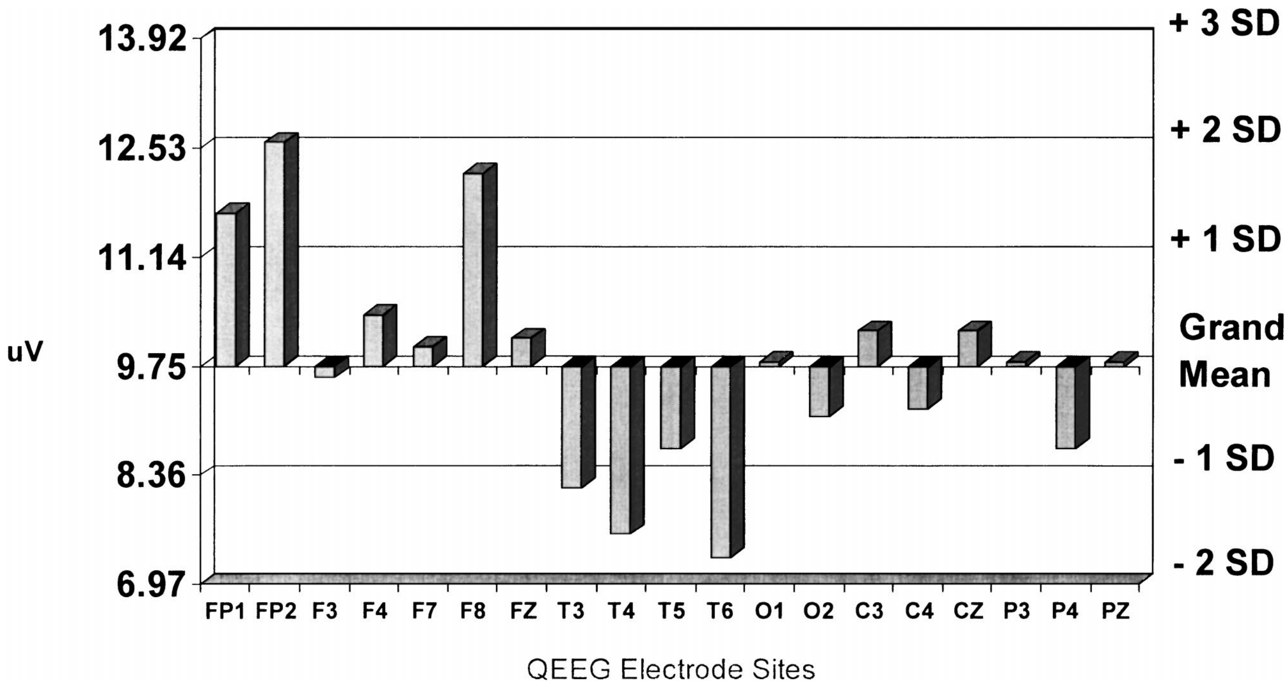

Fig. 5. Standard deviations for individual delta magnitudes (μV) derived from grand mean magnitude.

employs a single case, within-subject design that allows the examiner to focus on a syndrome, generate hypotheses of system dysfunction, and then systematically test these a priori hypotheses. Second, this approach allows the examiner to systematically assess multiple subsystems within the central nervous system for dysfunction to differentiate which subsystems are dysfunctional. Third, it allows the clinician to generate meaningful conclusions based on intraindividual neural system differences. In other words, the patient under consideration is used as his/her own control. Fourth, the syndrome analysis approach is frequently completed in a very short period of time, increasing its efficiency, minimizing the potential for fatigue, and reducing assessment confounds. Finally, this approach, as discussed earlier, contributes substantially and directly toward understanding functional neural systems and the development or the advancement of neuropsychological theory.

Likewise, the QEEG is an effective and flexible neuropsychological assessment tool. First, the QEEG may be used to make interhemispheric comparisons in patients with suspected cerebral dysfunctions. This allows the examiner to verify hypotheses generated by a previously completed syndrome analysis. Second, the QEEG allows the examiner to statistically analyze (e.g., descriptive and inferential analyses) multiple point comparisons of different electrode sites within a single individual. Using this statistical approach, the QEEG allows the examiner to employ a nomothetic method of analysis comparing the digital value of a specific site with all other sites. Therefore, because the patient serves as his or her own control, the QEEG is sensitive to the individual's unique premorbid level of cerebral functioning. Third, the QEEG allows the examiner to investigate cerebral functioning during different conditions (e.g., mood induction, cognitive tasks). Therefore, the examiner may experimentally manipulate conditions to systematically test these conditions in respect to specific a priori hypotheses. Finally, the QEEG may be repeated longitudinally to track the maintenance, decline, or improvement of the patient's cerebral functioning.

The QEEG evaluation serves as a critical test of the hypotheses generated by an examiner within a syndrome analysis approach to neuropsychological assessment. Additionally, it is useful in identifying unconfirmed areas of cerebral dysfunction, which can then be reassessed or monitored for change. In sum, the QEEG evaluation serves as an efficient and useful assessment tool when combined with the flexibility of the syndrome analysis approach. Traditional pencil-and-paper tests are useful and necessary tools for neuropsychological assessment; however, the contributions that neuropsychologists make to the understanding of brain–behavior relationships may be strengthened by combining neuropsychological assessment methods with supportive neurophysiological techniques.

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