

Quantitative EEG Findings Among Men Convicted of Murder

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Quantitative EEG data were collected from 20 men convicted of murder and sentenced to death. Measures of coherence, phase, amplitude asymmetry, and relative power from 19 scalp electrode sites during an eyes closed, resting condition were compared to a normative database. Measures significantly different from normal were tallied to determine electrode site locations with greatest concentrations of abnormalities. There were more right than left hemisphere abnormalities of coherence, phase, and amplitude asymmetry, and more anterior than posterior abnormalities of phase, amplitude asymmetry, and relative power. Bilateral frontal, right temporal, and parietal sites had the greatest concentrations of multiple abnormalities. Increased coherence and longer neural conduction times characterized the majority of coherence and phase abnormalities. The concentrations of frontal and right hemisphere abnormalities are discussed as relating to impairment, in executive functions, modulation of affect, and perception of affect in others. Such impairments perhaps in conjunction with adverse environmental events, are suggested as placing one at risk for violent behaviors. Relevance of these findings for future research, forensic neuropsychological assessments, and neurofeedback treatment is mentioned.

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There is general agreement that violence in America is a serious and growing problem. And, there is agreement that the sources of violence are complex, involving both environmental factors such as history of child neglect or abuse, and intrinsic factors such as neurological dysfunction. Persons convicted of murder and sentenced to death presumably committed violent acts that were most extreme. Knowledge of various characteristics of such persons, therefore, should be of special value in research into the roots of violence.

There have been very few published studies of psychological or neurological characteristics of persons condemned to death following murder convictions. A study of Lewis, Pincus, Feldman, Jackson, and Bard (1986) appears to be the most recent and comprehensive one. In that research, 15 death row inmates (13 men and 2 women) were evaluated using various combinations of psychiatric, neurological, and psychological assessment procedures. Subjects had been selected because of imminence of execution rather than due to apparent psychopathology, and therefore, were considered representative of inmates awaiting execution in the United States. Major findings of that study were that all subjects had histories of severe head injury, 12 had signs of neurological impairment, and 8 had major psychiatric disorders (schizophreniform psychosis or bi-polar disorder). Other studies of correlates of violence and other aggressive behaviors consistently report a higher incidence of neurological abnormalities in persons displaying such behaviors. These will be summarized briefly in the following sections.

Method

Subjects

Subjects were 20 men who had been convicted of one or more murders and sentenced to death. All were residents on death rows of southern states. Twelve subjects were white, seven black, and one Native American. Eighteen were right- and two left-handed. Mean age was 31.6 years ($SD = 5.6$), and mean IQ was 89.7 ($SD = 15.9$). The age range was 21 to 42, while IQ range was 66 to 118. Their defense attorneys to obtain information to be used during new trials or post-conviction relief hearings had referred all for QEEG assessment. Many were selected due to suspicion by their attorney that neurological dysfunction existed, and, if demonstrated, might serve as a mitigating factor in appeals to have the death sentence reduced to a life sentence.

Procedure

The QEEG assessments were completed in rooms on the "rows" on several different occasions over a four-year period. Lexicor Neurosearch 24 equipment was used in conjunction with Lexicor V151 software, and the appropriate size electrode cap from Electro-Cap International Incorporated * Approximately three minutes of EEG activity was sampled during an eyes closed, resting condition from 19 scalp electrode sites in the standard International 10-20 montage, with reference to ear lobes and ground just forward of site FZ. Sampling rate was 128 Hz, with 32K gain, and high pass filter off. Scalp electrode sites were prepared until impedance for each channel was at or below 5000 ohms. Subjects were seated in an upright position, and asked to relax, to sit as still as possible, and to try to keep eyes closed and still. Data collection began when observation of a subject's raw EEG on the computer monitor indicated eye and other movement artifacts were minimized as much as seemed likely to occur.

After EEG data collection was completed, the wave forms were visually inspected off-line, and artifacts eliminated prior to data analysis. This was done by a certified QEEG technician. Data analysis was completed using Neurorep software (Hudspeth, 1994) which incorporates the Thatcher Life Span EEG Reference Database (Thatcher, Walker, & Guidice, 1987). Specifically, measures of coherence (similarity of wave forms), phase (neural conduction time), and amplitude asymmetry (asymmetry of wave amplitude) in four different frequency bands are computed among all combinations of 8 right and 8 left intrahemispheric sites, and between homologous interhemispheric sites. Relative power in each of the same four frequency bands at each of 16 scalp electrode sites (excluding FZ, CZ, and PZ) also is calculated. The four frequency bands are delta (.5 to 3.5 Hz), theta (3.5 to 7.0Hz), alpha (7.0 to 13.0Hz), and beta (13 to 22Hz). A total of 832 raw scores are calculated, transformed to Z scores, and printed. Those Z scores differing significantly from the reference database norms for the subject's age, gender, and handedness are indicated (along with level of significance, i.e., .025, .005, .001). Pictorial representations of the subject's head (one for each of the four frequency bands) are included with the coherence, phase, amplitude asymmetry, and relative power score printout. These "connection maps" depict the 19 scalp electrode sites and include lines drawn between those sites with significantly abnormal coupling or "connections" (or, in the case of relative power, include circles around the abnormal sites). After all scores were printed, they were inspected visually for each subject to determine where abnormal ones were concentrated (i.e., frontal, posterior, left hemisphere, right hemisphere).

Results

The number of QEEG abnormalities found in individual subjects ranged from 10 to 131 (Mean 58.5; SD 35. 1). Since the scoring program used yields 832 measures and specifies those significantly different from normal at and beyond the .025 level, 21 abnormalities could be expected due to chance. Seventeen of the 20 subjects had more than 21 abnormalities. For the group as a whole and for all four variables, these abnormal scores were distributed quite evenly over the four frequency bands involved in the analyses. However, in individual cases there were concentrations of abnormalities in specific frequency bands.

Since no comparison groups were involved in this study (other than the database normative group), inferential statistical procedures were not relevant. Data analysis consisted of counts of abnormalities noted during visual inspection of scores.

An initial approach to the data involved simply scanning the pictorial representations of each subject's head to note whether or not there were obvious differential concentrations of abnormalities at certain locations (i.e., right, left, posterior, anterior). This is similar to what often is done in a clinical situation where the clinician scans various data in an attempt to discern meaningful patterns prior to more detailed analysis. A determination that there were more abnormalities at one location than at another was made only when it was obvious (i.e., did not require a precise tallying of abnormalities at each location to make the determination). If there was doubt, there was considered to be no difference. Using this conservative criterion, several patterns emerged as indicated in Table 1 which shows numbers of subjects with specific concentrations of abnormalities. Except for the relative power variable, right-left differences strongly favored more right hemisphere abnormalities. There were more anterior than posterior abnormalities for all variables except coherence, with the difference being especially strong for amplitude asymmetry. And when combinations of right and/or anterior abnormalities were considered in relation to left and/or posterior combinations, the former occurred more often for all variables. Collapsing these combinations across all variables resulted in a 45 to 19 count in favor of more right and/or anterior abnormalities.

Table 1
Incidence of Concentrations of QEEG Abnormalities

Locations	Variables			
	Coherence	Phase	Amplitude* Asymmetry	Relative* Power
Right > Left	10	13	9	2
Right < Left	4	1	1	5
Right = Left	6	6	10	13
Anterior > Posterior**	3	7	13	6
Anterior < Posterior	5	4	2	3
Anterior = Posterior	12	9	5	11
Right > Left and/or Anterior > Posterior	9	15	14	7
Left > Right and/or Anterior < Posterior	6	5	3	5

*Three subjects had no abnormalities of amplitude asymmetry, and eight had no relative power abnormalities. These are included in the right = left and anterior = posterior numbers.

**Sites T3, T4, C3, and C4 were not included in anterior-posterior comparisons.

A second approach to analysis involved locating specific electrode sites with the greatest concentrations of abnormalities. For the coherence, phase, and amplitude asymmetry variables, a site of concentration was defined as any site involved in three or more abnormal connections. Such sites which were found for at least five subjects (and incidence of subjects at each site) are shown in Table 2.

Table 2
Electrode Sites and Incidence of Multiple Abnormalities

Variable	Sites/Incidence
Coherence	O1(8), T6(7), FP2(7), O2(6), FP1(5)
Phase	P4(8), P3(6), T6(6), T4(6), T5(5), F8(5)
Amplitude Asymmetry	T4(12), FP2(8), FP1(7), F7(7), F4(7), T6(6), F8(5)

For all three variables, anterior and right hemisphere sites most often were involved in multiple abnormalities. More specifically, these sites generally were frontal, right temporal, and right parietal. A major exception was the high incidence of multiple coherence abnormalities observed at the left occipital (O1) site. There were eight subjects with no relative power abnormalities, and for the remaining 12, no concentration of abnormalities occurred at specific sites.

A final approach to data analysis involved precisely tallying specific scores and score patterns to determine those which occurred for 12 or more ($\geq 60\%$) subjects. It was decided, arbitrarily, that abnormalities found in 60% or more of the subjects probably are significant and would be worthwhile reporting. Results were as follows:

1. At least two coherence abnormalities involving coupling between any right frontal site (FP2, F4, F8) and any right posterior site (P4, T6, O2) were found for 12 subjects (60%).
2. Right hemisphere phase abnormalities exceeded left hemisphere phase abnormalities by a ratio of 1.4 to 1 or greater in 14 subjects (70%).
3. Right hemisphere phase abnormalities exceeded left hemisphere phase abnormalities by a ratio of 1.4 to 1 or greater, and/or the majority of phase abnormalities involved anterior (FP1, FP2, F3, F4, F7, F8) sites in 18 subjects (90%).
4. Right hemisphere amplitude asymmetry abnormalities exceeded left hemisphere abnormalities by a ratio of 1.4 to 1 or greater and/or the majority of multiple asymmetry abnormalities involved frontal sites (FP1, FP2, F3, F4, F7, F8) in 15 subjects (75%).
5. One or more amplitude asymmetry abnormalities existed between sites F8 and T4 for 12 subjects (60%).
6. Six or more abnormalities (considering coherence, phase, asymmetry, and relative power) were observed at a right posterior temporal site (T6) for 15 subjects (75%).

There were additional findings considered worth reporting. A higher incidence of increased, as opposed to decreased, coherence occurred in 15 subjects (75%). In four of the five exceptions, the decreased coherence predominantly was between right hemisphere sites. Abnormally increased coherence suggests decreased cortical differentiation, and often is observed in persons with a history of brain injury. Phase (neural timing) abnormalities predominantly involved positive Z scores (16 subjects; 80%, reflecting abnormally long neural conduction times. Both coherence and phase abnormalities are considered indicators of disturbed cortical integration and function

(Hudspeth, 1994). For 10 subjects the most frequent (modal) coherence abnormality involved coupling between relatively distant electrode sites (i.e., FP1, FP2, F3, F4, F7, or F8 to P3, P4, T5, T6, O1 or O2).

Discussion

Seventeen of the 20 subjects had more significantly abnormal scores than would have been expected due to chance, and in the 3 exceptions the abnormalities fit a pattern commensurate with the findings for most of the others (i.e., a concentration at right hemisphere sites). These findings seem to support those of other research which has found a high incidence of brain dysfunction in perpetrators of violence.

The findings of an especially high incidence of anterior (frontal lobe) abnormalities in a group of persons for whom there was suspicion of brain damage is not surprising, since frontal (and temporal) cortical areas are those most often damaged in closed head injuries (Richardson, 1990). Furthermore, a high incidence of frontal abnormalities in a population of braininjured violent offenders could be predicted considering that frontal areas are known to be heavily involved in mediating behavioral inhibition, judgment, self-monitoring, advance planning, and cognitive flexibility (Kolb & Wishaw, 1995). Problems with any of these "executive functions" would make it difficult to exert consistent voluntary control, thus putting one at risk for engaging in socially unacceptable behaviors, including some unlawful, violent behaviors.

The finding of a concentration of abnormalities in right hemisphere areas was not anticipated, but also makes sense from a neuropsychological perspective. That is, there is considerable evidence for right hemisphere specialization in perception of emotional stimuli and expression of emotion (Baer, 1989; Bryden & Ley, 1983). Persons with damage to the right cerebral hemisphere very often have problems interpreting emotion-related facial expressions, gestures, and voice quality (speech prosody) of others. Frequently they are described as impaired in social cognition (Pennington, 1991). If such persons find it abnormally difficult to "read" the facial expressions, gestures, and voice quality of others, they would be prone to misinterpret one emotion as another (fear as anger for example) and react inappropriately, perhaps with unwarranted violence. A combination of frontal and right hemisphere abnormalities (as noted in several subjects) may be an especially dangerous combination vis a vis expression of violent behaviors.

All persons (probably even the majority) with frontal lobe and/or right hemisphere brain lesions do not engage in violent behaviors, and certainly do not commit murder. As Nestor (1992) noted, it is likely that specific brain injuries put one at risk for violent behaviors, but other factors such as history of child abuse, serious mental illness, or substance abuse interact with brain dysfunction to trigger violence. This seemed likely for all subjects in the present study. That is, two had been diagnosed at one time with schizophrenia, most had histories of school learning problems, attention deficit disorder, and/or polysubstance abuse, several reported sexual abuse or major physical abuse, and most came from broken homes. In any particular case it is usually impossible to determine exactly the relative contributions of brain damage and environmental factors in an act of violence. Nevertheless, it is known that some brain lesions selectively affect emotions and behaviors (as opposed to more purely cognitive functions such as memory). And, as noted by Baer (1989), certain brain lesions can produce behavior which are not due to prior

personality or environmental factors.

The present study has several limitations. First, since most subjects were preselected as likely to have brain dysfunction, this precludes making generalizations about the actual incidence of QEEG indicators of brain lesions among death row inmates. To permit such generalization, future research in this area should involve random samples of such persons. Furthermore, one or more comparison groups should be included. A random sample of death row inmates (or other convicted murderers) could be compared to a random sample of persons convicted of non-violent crimes, and/or to a randomly selected group of persons with no history of criminal behaviors. Another interesting comparison group would be persons with histories of brain damage and undesirable childhood experiences, but no history of violent behaviors. Use of such comparison groups should help delineate specific QEEG abnormalities (and, by implication, the brain locations and neural systems) uniquely associated with violent behaviors.

A second limitation is that abnormal QEEG scores do not necessarily indicate brain dysfunction. A score might be outside the normal range, but reflect a superior form of the brain organization, or a successful compensation for an earlier injury or developmental abnormality. Further neurological or neuropsychological assessment would be needed to validate that abnormal scores or score patterns are, in fact, reflecting brain dysfunction in any individual case. With these limitations in mind, there does appear to be support in these findings for a high incidence of abnormality of brain function among convicted murderers such as the subjects of this study. That is, although subjects were selected as persons suspected of having brain damage, they included approximately 30% of one state's death row population and that subgroup's score patterns were similar to those of the group as a whole.

Any QEEG investigation should consider known effects of drugs on the EEG. This was not done in any systematic manner in this study. Although two potential subjects were eliminated from the study due to extreme diffuse slowing of the EEG (apparently due to drug effects), others were included even though taking medications with potential effects on some EEG parameters, provided such effects were not obvious during visual inspection of the raw EEG wave forms.

The most frequently observed abnormalities in this study involved measures of coherence, phase, and amplitude asymmetry rather than relative power. This suggests that abnormal timing relationships among certain cortical areas may be especially important variables to consider in future research on the neurological correlates of violence. At present, QEEG measures are the most readily available, accurate measures of these variables.

The evidence found here for abnormalities of brain electrical activity in persons convicted of extreme violence has relevance for the rapidly developing field of neurofeedback. Clinicians in that field are demonstrating that one's learning of voluntary control over EEG parameters via appropriate feedback can lead to remission of symptoms of various disorders (e.g., attention deficit disorder, depression, alcoholism, chronic fatigue syndrome), including symptoms of traumatic brain injury. Results of this research may serve as a guide to clinicians regarding those EEG variables and locations which should be given special attention when working with violent brain injured clients. Furthermore, these findings suggest the potential value of including QEEG assessment in comprehensive forensic neuropsychological evaluations, and they should serve as a

rich source of hypotheses for future controlled research on the correlates of violence.

References

Adams, J. J., Meloy, J., & Moritz, M. (1990). Neuropsychological deficits and violent behavior in incarcerated schizophrenics. Journal of Nervous and Mental Disease, 178(4), 253-256.

Baer, D. M. (1989). Organic personality syndromes. In A. Lazare (Ed.), Outpatient psychiatry: Diagnosis and treatment (pp. 351-360). Baltimore: Williams and Wilkins.

Bryden, M. P., & Ley, R. G. (1983). Right hemispheric involvement in the perception and expression of emotion in normal humans. In K. Heilman & P. Satz, Neuropsychology of human emotion. New York: Guilford Press.

Bryant, E. T., Scott, M. L., Tori, C. D., & Golden, C. J. (1984). Neuropsychological performance on tests of frontal-lobe functioning and aggressive behavior in men. Journal of Abnormal Psychology, 103, 832-835.

Hudspeth, W. J. (1994). Neurorep User's Guide. Stockton, CA: Neuropsychometric Laboratory.

Kolb, B., & Wishaw, I. (1996). Fundamentals of human neuropsychology. New York: W Freeman & Company.

Lewis, D. O., Lovely, R., Yeager, C., & Fermina, D. D. (1989). Toward a theory of the genesis of violence: A follow-up study of delinquents. Journal of the American Academy of Child and Adolescent Psychiatry, 28(3), 431-436.

Lewis, D. O., Pincus, J. H., Feldman, M., Jackson, L., & Bard, B. (1986). Psychiatric, neurological and psychoeducational characteristics of 15 death row inmates in the United States. American Journal of Psychiatry, 143(7), 838-845.

Mednick, S. A., Brennen, R., & Kandel, E. (1988). Predisposition of violence. Aggressive Behavior, 14(1), 25-33.

Nestor, R G. (1992). Neuropsychological and clinical correlates of murder and other forms of extreme violence in a forensic psychiatric population. The Journal of Nervous and Mental Disease, 180(7), 418-423.

Pennington, B. (1991). Diagnosing learning disorders: A neuropsychological frame -work. New York: Guilford Press.

Richardson, J. T (1990). Clinical and neuropsychological aspects of closed head

injury. Bristol, PA: Taylor & Francis, Inc.

Tancredi, L. R., & Volkow, N. (1988). *Neural substrates of violent behavior: Implications for law and public policy* International Journal of Law and Psychiatry, 11, 13-49.

Thatcher, R., Walker, R., & Guidice, S. (1987). *Human cerebral hemispheres develop at different rates and ages.* Science, 236, 1110-1113.

Weller, M. P. (1986). *Medical concepts in psychopathy and violence.* London: Friern Whittington Hospital.

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