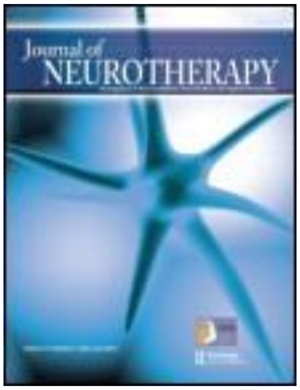

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

Quantitative EEG Findings in Convicted Murderers

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Published online: 08 Sep 2008.

To cite this article: Jennifer M. C. Vendemia PhD , Kelly E. Caine BA & James R. Evans PhD (2005) Quantitative EEG Findings in Convicted Murderers, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 9:3, 5-29

To link to this article: http://dx.doi.org/10.1300/J184v09n03_02

SCIENTIFIC ARTICLES

Quantitative EEG Findings in Convicted Murderers

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SUMMARY. In this study we examined the QEEGs of convicted murderers ($n = 73$) living on death row, referred by attorneys, and compared them to a control group ($n = 23$) referred for neuropsychological evaluation by physicians, attorneys, or a State Vocational Rehabilitation Department. The individuals living on death row committed murders

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[Co-indexing entry note]: "Quantitative EEG Findings in Convicted Murderers." Vendemia, Jennifer M. C., Kelly E. Caine, and James R. Evans. Co-published simultaneously in *Journal of Neurotherapy* Vol. 9, No. 3, 2005, pp. 5-29; and: *Fo-rensic Applications of QEEG and Neurotherapy* (ed: James R. Evans) 2005, pp. 5-29.

doi:10.1300/J184v09n03_02

during robberies, drug deals, rapes, and crimes of passion. They all had suspected or known histories of traumatic brain injury; some had comorbidities of schizophrenia, depression, and other psychiatric diagnoses. The individuals in the control group had a history of head trauma resulting primarily from motor vehicle accidents; a few had the comorbidity of depression. The murderers were randomly divided into two separate groups for comparisons with the control group. Coherence (within broad-band alpha) scores were calculated between all scalp electrode sites and fast-fourier spectral analyses were performed for each channel for two QEEG samples of at least 60 seconds (after artifact removal) recorded during eyes-closed. Spatial principal components derived from the mean peak-to-peak magnitude were calculated for several bands of EEG and submitted to 2×2 (death penalty $\times$ handedness) ANOVAs. Murderers had reduced mean peak-to-peak magnitude across all bands similar to that seen in broad spectrum EEG studies of aging. At anterior regions murderers had reduced high theta and high alpha suggesting impaired attention. There was significantly higher coherence in controls in the alpha range between and among central and posterior sites. These findings are used to support the theory that time on death row facilitates "cognitive aging."

KEYWORDS. QEEG, cognitive impairment, murderers, death row, aging

INTRODUCTION

The number of murderers living on death row and the amount of time they spend on death row has been increasing steadily since the revision of state capital punishment laws in 1976. Many studies have reported brain abnormalities in individuals convicted of murder, and these abnormalities may be exacerbated by the pattern of cognitive and physical decline documented in individuals who endure incarceration on death row (Johnson, 1979). In the only published quantitative EEG (QEEG) study of individuals on death row, Evans and Park (1997) compared the QEEG of such incarcerated individuals to established norms and found several significant differences. Although focal brain damage and cognitive impairment are highly correlated with violent crime and murder, they are not predictive. The current study attempted to extend previous

QEEG findings and to separate pre-existing focal brain damage from pathology related to death row by comparing two groups of individuals serving time on death row to a group of matched controls.

Evidence in the literature suggests that violent offenders very frequently have brain abnormalities (for review and meta-analysis, see Cunningham & Vigen, 2002). In eight studies reporting the neurological impairments of individuals on death row, three identified minor or major neurological impairments in 33 to 75% of cases (Freedman & Hemenway, 2000; Lewis, Pincus, Feldman, Jackson, & Bard, 1986; Lewis et al., 1988); four identified head trauma in 24 to 100% of the cases (Freedman & Hemenway, 2000; Frierson, Schwartz-Watts, Morgan, & Malone, 1998; Lewis et al., 1988, Lewis et al., 1986) and five identified abnormal EEG or PET scans in 50 to 100% of cases (Evans & Park, 1997; Frierson et al., 1998; Raine, Buchsbaum, & LaCasse, 1997; Raine et al., 1994; Raine et al., 1998).

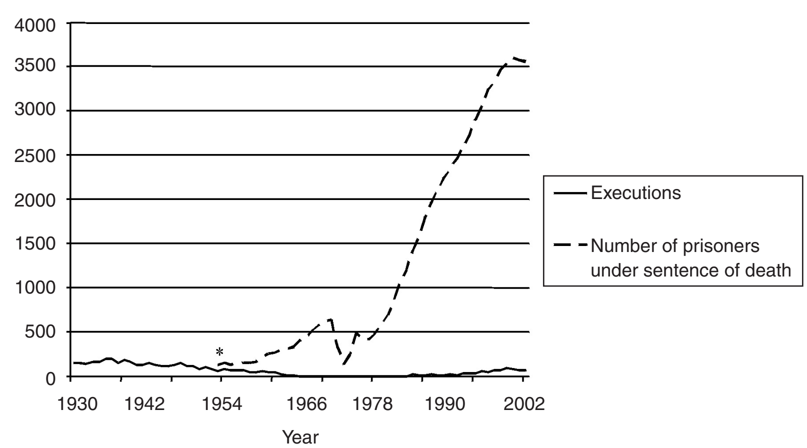
Evans and Park (1997) compared the QEEG of 20 murderers to norms set in the Thatcher Life Span EEG Reference Database (Thatcher, Walker, & Guidice, 1987) for coherence (i.e., similarity of waveforms), phase (i.e., neural conduction time), and amplitude asymmetry (i.e., asymmetry of wave amplitude) in delta, theta, alpha, and beta frequency bands. In twelve subjects they found coherence abnormalities involving any right frontal site (Fp2, F4, F8) and any right posterior site (P4, T6, O2). In murderers they found more right hemisphere phase abnormalities than left hemisphere phase abnormalities and a majority of phase abnormalities in the anterior regions. Twelve subjects had one or more amplitude asymmetries between F8 and T4, and 15 subjects had abnormally increased coherence.

A PET study comparing 41 murderers pleading not guilty by reason of insanity to 41 controls found reduced glucose metabolism in prefrontal cortex, superior parietal cortex, left angular gyrus, and the corpus callosum (Raine et al., 1997). A second PET study comparing nine affective (murder without premeditation) murderers to matched controls found a pattern of lower prefrontal activity and higher subcortical activity in murderers (Raine et al., 1998).

However, pre-existing brain abnormalities may only partially explain the locus and frequency of cortical abnormalities among death row inmates. Death row has been characterized as an extremely stressful environment. There is the stress of impending execution (Bluestone & McGahee, 1962); there are stressors based on the community dynamics with prisoners not serving time on death row as well as with guards (Arrigo & Fowler, 2001; Cunningham & Vigen, 2002), and there are physical stressors resulting from substandard living conditions (Cunningham & Vigen, 2002). Time spent on death row is associated with a cluster of psychological factors which some researchers believe may lead to "personality deterioration or actual insanity" (Johnson, 1979). These psychological symptoms include: (a) a sense of helplessness and defeat, (b) a sense of widespread and diffuse danger, (c) a perception of helpless vulnerability, (d) emotional emptiness, (e) loneliness and a deadening of feelings, and (f) a decline in mental and physical acuity. Lengthy stays on death row can exacerbate these symptoms (Gallermore & Panton, 1972).

Due to changing conditions in the justice system, inmates are enduring more time on death row which may lead to even greater changes in psychological state. Since the revision of state capital punishment laws in 1976 the number of inmates on death row has increased significantly while the number of inmates executed annually has remained constant (see Figure 1). This pair of trends has resulted in a growing population of inmates living on death row. In 2002, inmates were spending an average of 8.64 years on death row (*SDx* = 5.79). This was up from 1992 when inmates were spending an average of 6.31 years on death row (*SDx* = 3.63; U.S. Department of Justice, 2004).

FIGURE 1. Trends for prisoners on death row and the number of executions in the period from 1930 until 2002 (based on National Archive of Criminal Justice Data).



*Number of prisoners under sentence of death unavailable for period before 1953.

The combination of brain abnormalities of violent offenders and the psychological consequences of spending time on death row may have a serious impact on mental status. The deterioration of mental acuities has been found to include drowsiness, listlessness, mental slowness, confusion, and forgetfulness (Johnson, 1979). These factors related to spending time on death row may impact the EEG. For example, cognitive decline may impact broad band beta, as a decrease in broad band beta power has been reported in normal aging subjects experiencing cognitive decline (Williamson et al., 1990). A similar trend has been observed in broad band alpha (Soininen et al., 1991). Perhaps also relevant are the findings of Adler, Bramesfeld, and Jajcevic (1999) who reported an increase in absolute power in the delta and theta bands in depressed subjects with mild cognitive impairments.

Broad band EEG can be subdivided into narrow bands that have been associated with specific cognitive activities. For example, broad band theta can be differentiated into two discrete bands associated with unique types of mental activity (for review, see Schacter, 1977). Increased low theta (4-5.45 Hz) activity correlates with decreased arousal and increased drowsiness, while high theta (6-7.45 Hz) activity correlates with increased attention and cognitive load. High theta normally is enhanced during tasks involving working memory (Klimesch, 1996) and has been associated with focused cognitive activities (Inouye, Ishihara, Shinosaki, Toi & Ukai, 1988; Ishihara & Yoshi, 1972; Mizuki, Kajimura, Kaie, Suetsuigi, 1992; Ramos, Corsi-Cabrera, Guevara, & Arce, 1993).

We hypothesized that as low theta is negatively correlated with arousal such as that produced during states of anxiety, individuals serving time on death row would produce less low theta than matched controls would produce. As high theta is positively correlated with cognitive activities, individuals on death row with minimal intellectual stimulation would produce less high theta than matched controls would produce.

Within the broad band alpha range, factor analytic work indicates discrete alpha frequency bands (Hermann & Schaerer, 1986; Mecklinger, Kramer, & Strayer, 1992). Individuals who self-reported poor sustained attentional abilities generated significantly more low alpha spectral magnitude than did high sustained attention subjects while performing tracking or decision making tasks; mid and high alpha bands did not discriminate (Crawford, Knebel, Vendemia, Kaplan, & Ratcliff, 1995). High sustained attention individuals have been found to generate more high alpha compared to low sustained attention individuals (Crawford, Clark, & Kitner-Triolo, 1996).

Because individuals on death row report drowsiness, listlessness and mental slowness (Gallermore & Panton, 1972), we predicted that they would generate more low alpha than matched controls would generate. Additionally, as individuals on death row report impaired cognitive abilities, perhaps related to impaired attention, it was expected that individuals on death row would have decreased high alpha when compared to matched controls.

Broad band beta activity can also be subdivided into discrete subbands. Low beta activity in the 11-15 Hz (beta-13) range has been associated with visual tracking (Mann, Sterman, & Kaiser, 1996), and beta activity in the 16-24 Hz (beta-16) range has been associated with enhanced attentional processing (Crawford et al., 1996; Crawford et al., 1995). Beta 16 also has been correlated with vigilance in individuals with more sustained attentional abilities (Crawford et al., 1996; Crawford et al., 1995). As observed in studies of cognitive impairment and depression, it was expected that participants on death row would generate less beta-13 and beta-16 compared to matched controls.

In the current study we examined the QEEGs of seventy-three individuals convicted of murder, who at the time of their evaluation were living on death row. Based on the work of Raine and colleagues (Raine et al., 1997, Raine et al., 1994, Raine et al., 1998, see discussion below) we compared their QEEGs to those of a control group of neurologically impaired, matched controls. We examined two classes of dependent variables: (a) mean peak-to-peak magnitude within low theta (3.5-5.45 Hz), high theta (5.5-7.45 Hz), low alpha (7.5-8.45 Hz), mid alpha (8.5-11.45 Hz), high alpha (11.5-13.45 Hz), beta-13 (13.5-16.45 Hz), and beta-16 (16.5-19.45 Hz) bands; and (b) coherence within broad band alpha (7.5-13.45 Hz).

Patterns of mean peak-to-peak power across electrode sites and coherence between electrode sites were explored using principal components analysis followed by statistical tests of the hypotheses. This strategy allows one to identify regions of patterns activation, and to test those patterns specifically. Several researchers have advocated the use of multivariate statistics in the exploration of EEG data due to the multivariate nature of the data as well as the applicability of these types of results to neurophysiological models of cognition (Barceló & Gale, 1997; Barceló, Gale, & Hall, 1995; Tucker & Roth, 1984). Reducing the dimensionality of an EEG dataset with principal components and then testing hypotheses is specifically suggested (Barceló & Gale, 1997; Duffy, Bartels, & Neff, 1986).

Patterns of coherence were predicted to discriminate death row inmates and matched controls. Evans and Park (1997) hypothesized that the observed patterns of increased coherence were related to decreased cortical differentiation. Based on these findings we expected that individuals serving time on death row would have abnormalities of increased coherence when compared with the control group. Additionally, based on Evans and Park (1997), we predicted that individuals serving time on death row would have more abnormalities of coherence in the right hemisphere than in the left hemisphere and more abnormalities involving coupling between relatively distant electrode sites (Fp1, Fp2, F3, F4, F7, or F8 to P3, P4, T5, T6, O1, or O2).

METHOD

Participants

The participants were selected from an archival data set from 10 years of neuropsychological evaluations. The overall set was divided into two groups of murderers based on date of collection and then separately compared to a single control group. Murderers in both groups (n = 46 and n = 27) were referred by attorneys. The ages of murderers in group 1 ranged from 19 to 53 (Mx = 30.67, Sdx = 8.62), and the ages of those in group 2 ranged from 19 to 52 (Mx = 32.00, Sdx = 9.54). The mean age of murderers in both groups was lower than the mean age of all individuals on death rows in 2002 (Mx = 39.00; Bonczar & Snell, 2003). All participants in this study were male, and this matches the overall demographic of prisoners on death row (male = 98.6%, female = 1.4%; Bonczar & Snell, 2003). Fifty-four percent of all inmates under sentence of death in 2002 were Caucasian, 44% were African-American, 12% were Hispanic, and 2% fit other categories (Bonczar & Snell, 2003), while 64% of the current sample were Caucasian and 36% were African-American. The median educational level of inmates in groups 1 and 2 was 10.15 and 10.68, respectively. This was slightly lower than the median educational level of 11th grade for all inmates on death row in 2002 (Bonczar & Snell, 2003). The murders in this study were convicted of crimes including robbery, drug deals, rape, and crimes of passion; they met the definition proposed by Raine et al. (1994) of affective murderers. Report data for time spent on death row was available for a subset of 26 inmates. These inmates spent between 2 years and 16 years, four months on death row (*Mx* = 3381 days, *SDx* = 1269 days).

The control group participants ($n = 23$) were referred by physicians, attorneys, or a State Vocational Rehabilitation Department. The decision to use a neuropsychologically impaired control group was based on PET studies of murderers (Raine et al., 1997; Raine et al., 1994; Raine et al., 1998), and a recommendation in Evans and Park (1997). In this research, the control group was matched on a variety of demographic characteristics. Although there has been some debate regarding appropriate controls for murderers (i.e., Ladds & Trachtenburg, 1995), most researchers advocate the strategy of matching on brain trauma and psychiatric illness when studying murderers. As can be seen from Table 1, the control group did not significantly differ from either group of murderers in age, IQ or handedness. However, the control group did have a slightly higher education level [$t(67) = 2.11$, $p = .001$].

Reading level and arithmetic level (standard scores) results from the Wide Range Achievement Test (WRAT-R; Jastak & Wilkinson, 1984 or WRAT-3; Wilkinson, 1993) were not significantly different for murderers and controls, $t(43) = -.85$, $p = .20$, $t(21) = -.11$, $p = .91$. The means and standard deviations are given in Table 1. Scores for both groups were below average.

TABLE 1. Demographic Variables for Murderers on Death Row in Groups 1 and 2, as well as the Matched Control Group.

Group	AGE	IQ	Education	Hand		WRAT (Standard Score)	
				R	L	Reading	Arithmetic
Study 1: Murderers (n = 46)				33	13		
M (SD)	30.67 (8.62)	91.83 (15.13)	10.15 (1.86)			88.17 (17.64)	83.17 (15.79)
Study 2: Murderers (n = 27)				21	6		
M (SD)	32.00 (9.54)	92.96 (12.81)	10.68 (2.44)			*	*
Control Group (n = 23)				14	9		
M (SD)	40.00 (14.31)	91.8 (16.28)	12.26 (3.06)			84.39 (17.04)	78.50 (12.77)
Total (N = 96)				68	28		
M (SD)	34.22 (10.82)	92.20 (14.74)	11.03 (2.45)			85.65 (17.21)	82.83 (13.53)

*Data unavailable.

Procedure

EEG was recorded with a Lexicor Medical Technologies Neurosearch-24 system (Lexicor Technologies, Boulder, CO) from anterior frontal (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central, (C3, C4), anterior temporal (T3, T4), posterior temporal (T5, T6), parietal (P3, P4), occipital (O1, O2), and midline (Fz, Cz, Pz) sites according to the international 10-20 system (Jasper, 1958) using an appropriately sized electrode cap (Electro-Cap International, Inc., Eaton, OH). Reference was to linked earlobes (A1, A2). Resistance was kept below 5000 ohms. EEG signals between 1 and 32 Hz were amplified with a gain setting of 32K. The sampling rate was 128 samples per second. A 60 Hz notch filter was used to reduce electrical noise.

Three minutes of EEG activity was sampled during an eyes-closed resting condition while participants sat 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 was initiated when each participant's raw EEG indicated eye and other movement artifacts were as minimal as deemed possible.

Recordings of the individuals convicted of murder were completed in rooms on "death rows" over a 10-year period, while recordings of matched controls were conducted in clinicians' offices over the same period.

Data Analyses

EEG data were screened for artifact before conversion into Neuroscan format (Neuroscan Inc., Palo Alto, NM). Fast-fourier spectral analyses were performed for each channel (1-32 Hz) and mean magnitude was calculated for the following frequencies: low-theta (3.5-5.45 Hz), high-theta (5.5-7.45 Hz), low-alpha (7.5-8.45 Hz), mid-alpha (8.5-11.45 Hz), high-alpha (11.5-13.45 Hz), beta-13 (13.5-16.45 Hz), and beta-16 (16.5-19.45 Hz). Data were log transformed due to the commonly observed positively skewed frequency distribution of EEG with high kurtosis (Sterman, Mann, Kaiser, & Suyenobu, 1994).

RESULTS

Narrow Band Frequency Analyses

Principal components analysis with varimax rotation was run for each of the frequency bands across the 19 channels of data. Principal components allows for the extraction of related variance across electrode sites. When more than one effect occurs within a band, these effects can be evaluated separately. Additionally, variance not related to any specific component can be eliminated from further analysis.

The principal components from each band were individually submitted to 2×2 (group $\times$ handedness) ANOVAs. Component loadings were evaluated to localize effects across specific electrode sites on the scalp. Correlations were performed between the components and the demographic variables of IQ, age, and education.

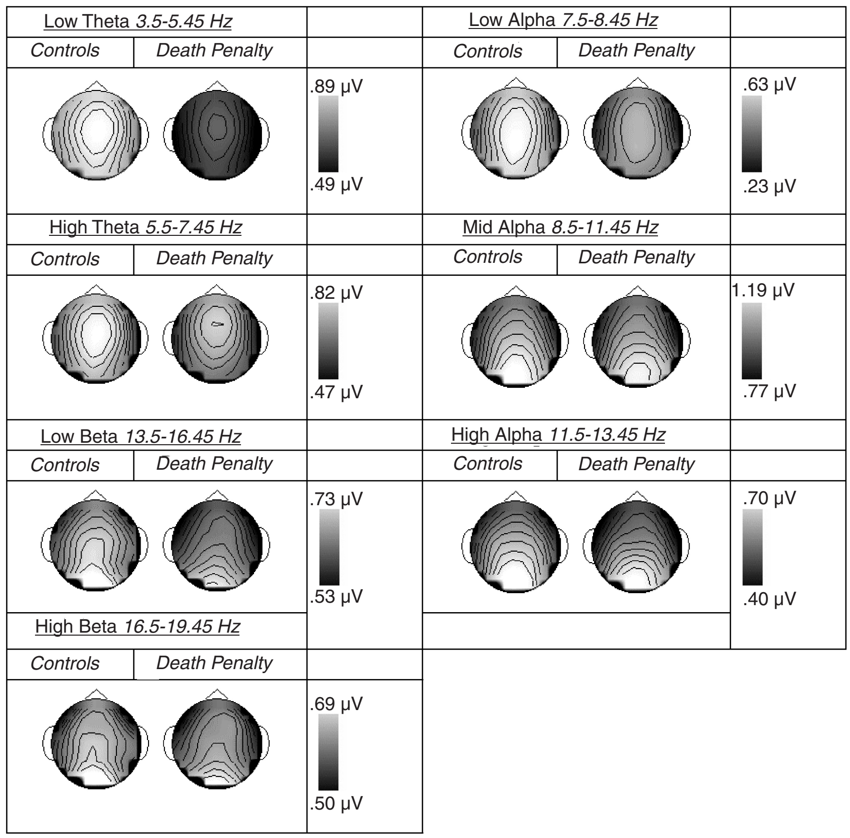
We hypothesized that time spent on death row would impact components associated with the low and high theta as well as the low and high alpha. In order to test this hypothesis, we calculated correlations between the components and the number of days spent on death row for the subset of 26 death row inmates for whom we had these data.

Death Row Group 1

Low-Theta (*3.5-5.45 Hz)*. Two components accounted for 90.16% of the variance in low-theta scores. The first component had the strongest loadings on activity in the frontal regions (Fp1, Fp2, Fz, F3, F4, F7, F8), while the second component had the strongest loadings on activity in the parietal and occipital regions (P3, P4, O1, O2). A 2×2 (group $\times$ handedness) ANOVA revealed no significant differences between groups for either component. Figure 2 shows mean low theta activity in convicted murderers and neurologically impaired matched controls. There was a significant negative correlation between the first low theta component and age ($r = -.335$, $p = .005$), and a trend toward a significant positive correlation between the second low theta component and education ($r = .232$, $p = .055$). In the subset of inmates for whom time spent on death row was available ($n = 26$), there was a significant correlation between the second low theta component and time spent on death row such that individuals who had spent longer on death row generated more low theta in parietal and occipital regions ($r = .411$, $p = .018$).

High-Theta (*5.5-7.45 Hz)*. A single component with loadings in frontal and parietal regions (Fp1, Fp2, Fz, F3, F4, Pz, P3, P4) explained 87.39% of the variance in high-theta activity. A 2×2 (group $\times$ handedness) ANOVA revealed a main effect for group, $F(1, 69) = 6.27$, $p = .015$, such that convicted murderers generated less high-theta compared to controls. Additionally, there was an interaction between group and handedness such that left-handed controls generated the most high-theta, followed by right-handed controls, then by right-handed con-

FIGURE 2. Mean log transformed magnitude of EEG in sub-bands of theta, alpha, and beta in individuals in Group 1 who received the death penalty and matched controls.



victed murderers, and then left-handed convicted murderers, $F(1, 69) = 4.34$, $p = .041$. Figure 2 shows mean high theta magnitude in convicted murderers and controls. There was a significant positive correlation between high-theta component and education ($r = .260$, $p = .031$).

Low-Alpha (*7.5-8.45 Hz*). A single component with loadings in the frontal and central regions (Fp1, Fp2, Fz, F3, F4, Cz, C3, C4) explained 91.90% of the variance in low-alpha activity. A 2 × 2 (group × handedness) ANOVA revealed a main effect for group such that convicted murderers had much lower scores on this component than controls, F(1,

69) = 9.97, $p = .002$. Figure 2 shows mean low alpha magnitude in convicted murderers and controls. There was also a significant interaction, $F(1, 69) = 5.89$, $p = .03$. Left-handed controls scored the highest on the low alpha component, followed by right-handed controls, then right-handed individuals convicted murderers, and finally left-handed convicted murderers. There were no significant correlations between the low-alpha component and demographic data.

Mid-Alpha (*8.5-11.45 Hz)*. A single component explained 91.90% of the variance in mid-alpha activity. A 2 × 2 (group × handedness) ANOVA revealed no significant effects. Figure 2 shows mean mid-alpha magnitude in murderers and controls. There was a significant negative correlation between the mid-alpha component and age ($r = -.286$, $p = .017$); younger individuals tended to have higher scores on this component than older individuals.

High-Alpha (*11.5-13.45 Hz)*. Two components explained 90.71% of the variance in the high-alpha band. The first component loaded most strongly in the frontal and central regions (Fz, FP1, FP2, F3, F7, F8, C3, C4) while the second component loaded most strongly in the parietal and temporal regions (P3, P4, T3, T4, T5, T6). A 2 × 2 (group × handedness) ANOVA showed that controls had much higher scores on the first component than murderers, $F(1, 69) = 4.63$, $p = .035$. No significant differences were identified for the second high-alpha component. Figure 2 shows mean high-alpha magnitude in convicted murderers and controls. There was a trend towards a negative correlation between age and the second high-alpha component such that older individuals had lower scores on this component compared to younger individuals ($r = -.223$, $p = .065$).

Beta-13 Activity (*13.5-16.45 Hz)*. Two components explained 87.91% of the variance in the Beta-13 band. The first component loaded most strongly in the parietal, occipital, and posterior temporal region (P3, P4, O1, O2, T5, T6), while the second component loaded most strongly in the frontal and central regions (FZ, FP1, FP2, F3, F7, F8, C3, C4). A 2 × 2 (group × handedness) ANOVA identified no significant differences for the first Beta-13 component, but a trend was identified for the second component, $F(1, 69) = 3.53$, $p = .063$. Those individuals on death row produced significantly less beta-13 than did individuals in the control group. No significant correlation between Beta-13 and the demographic variables was identified. Figure 2 shows mean Beta-13 magnitude in convicted murderers and controls.

Beta-16 Activity (*16.5-19.45 Hz)*. Two components explained 84.85% of the variance in the beta-16 band. The first component loaded heavily in the parietal, occipital, and posterior temporal region (P3, P4, O1, O2, T5, T6). The second component loaded in the frontal, central, and anterior temporal regions (FP1, FP2, F3, F7, F8, C3, C4, T3, T4). Group by handedness ANOVAs found no significant differences in these components, and no correlations were identified between the components and demographic variables. Figure 2 shows mean beta-16 magnitude in convicted murderers and controls.

Death Row Group 2

Low-Theta (*3.55-5.45 Hz*). A single component explained 92.17% of the variance in low-theta scores. This component loaded on sites over the entire surface of the scalp. A 2 × 2 (group × handedness) ANOVA revealed that convicted murderers generated less low theta than controls, $F(1, 51) = 42.73$, $p = .000$. There were no significant correlations between low theta and demographic variables.

High-Theta (*5.5-7.45 Hz*). A single component explained 94.10% of the variance in high-theta activity. This component was strongly correlated with activity over the entire surface of the scalp. A 2 × 2 (group × handedness) ANOVA revealed a main effect for group, $F(1, 51) = 35.22$, $p = .000$, such that murderers generated less high-theta. There were no significant correlations between this factor and demographic variables.

Low-Alpha (*7.5-8.45 Hz*). A single component with strongest loadings in the frontal and central regions (Fp1, Fp2, F3, F4, Cz, C3) explained 93.12% of the variance in low-alpha activity. A 2 × 2 (group × handedness) ANOVA revealed a main effect for group such that murderers had much lower scores on this component than those in the control group, $F(1, 51) = 34.53$, $p = .000$. There were no significant correlations between the low-alpha component and demographic data.

Mid-Alpha (*8.5-11.45 Hz*). A single component with loadings in the frontal and central regions (Fz, F3, Cz, C3, C4) explained 92.52% of the variance in mid-alpha activity. A 2 × 2 (group × handedness) ANOVA revealed that murderers generated less mid-alpha compared to controls, $F(1,51) = 39.30$, $p = .000$. There were no significant correlations between the data and demographic variables.

High-Alpha (*11.5-13.45 Hz*). A single component with strongest loadings in the frontal and central regions (Fp1, Fp2, Fz, F3, F8, Cz, C3) explained 89.08% of the variance in the high-alpha band. A 2 × 2 (group × handedness) ANOVA showed that controls had much higher scores on this component than did murderers, $F(1, 51) = 27.26$, $p = .000$.

Beta-13 (*13.5-16.45 Hz)*. A single component with loadings in the central and parietal regions (C3, C4, Pz, P4) explained 92.28% of the variance in the Beta-13 band. A 2 × 2 (group × handedness) ANOVA revealed that controls generated more beta-13 compared to murderers, $F(1, 51) = 54.82$, $p = .000$. No significant correlation between beta-13 and the demographic variables was identified.

Beta-16 (*16.5-19.45 Hz)*. A single component with loadings in the frontal, central, and parietal regions (Fz, F3, Cz, C3, C4, P3, P4) explained 90.68% of the variance in the Beta-16 band. A 2 × 2 (group × handedness) ANOVA found that murderers produced less Beta-16 than controls, $F(1, 51) = 56.71$, $p = .000$. No correlations were identified between the components and demographic variables.

Summary of Narrow Band Frequency Analyses

As shown in Table 2, the mean power magnitude of the EEG within each of the frequencies generally was lower for murderers than matched controls. In group 2, these findings were significant across all bands while in group 1, this pattern was significant in high-theta, low- and high-alpha, and in beta-13. For mean power magnitude, generally consistent findings with respect to spatial distribution across both groups were identified in the high-theta, low-alpha, and high-alpha bands.

TABLE 2. Summary of Within-Band Mean Power Magnitude Differences Between Each Group of Murderers and the Control Group

EEG Frequency	Significant Differences Between Murderers and Controls			
	Group 1		Group 2	
	Direction	Sites	Direction	Sites
Low-Theta	n.s.		M < C***	Fz, F3, F4, Cz, C4, Pz, P3, P4
High-Theta	M < C*	Fp1, Fp2, Fz, F3, F4, Pz, P3, P4	M < C***	Fz, F3, F4, Cz, C4, Pz, P3, P4
Low-Alpha	M < C**	Fp1, Fp2, Fz, F3, F4, Cz, C3, C4	M < C***	Fp1, Fp2, F3, F4, Cz, C3
Mid-Alpha	n.s.		M < C***	Fz, F3, Cz, C3, C4
High-Alpha	M < C*	FP1, FP2, Fz, F3, F7, F8, C3, C4	M < C***	Fp1, Fp2, Fz, F3, F8, Cz, C3
Beta-13	M < C[T]	FP1, FP2, Fz, F3, F7, F8, C3, C4	M < C***	C3, C4, Pz, P4
Beta-16	n.s.		M < C***	Fz, F3, Cz, C3, C4, P3, P4

* p< .05, ** p < .02, *** p < .001, [T] p = .06

Coherence Analyses

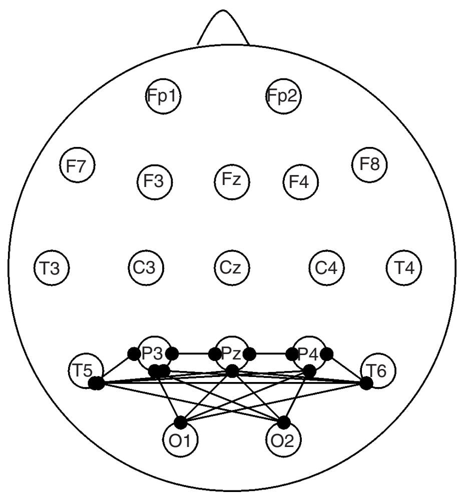
Coherence (i.e., similarity of waveforms) between each set of electrodes was calculated for broad band alpha (7.45-12.45 Hz) using NeuroRep Software (Hudspeth, 1994). Coherences between all possible electrode sites were submitted to a principal components analysis followed by varimax rotation in order to identify patterns of coherences across the groups. This was followed by a t-test to determine which patterns of coherences differentiated murderers and matched controls. Additionally, correlations were run between those patterns of coherences that differentiated between murderers and the comparison group and time spent on death row.

For the first group of murderers, 92.90% of the variance in the pattern of coherence between the murderer group and the comparison group was accounted for by 19 components. Of these, the first 11 components accounted for meaningful proportions of the variance. For the second group of murderers and the comparison group, 94.53% of the variance was explained by 19 components. Of these, the first 12 components accounted for meaningful proportions of the variance. The components which explained meaningful proportions of the variance following varimax rotation were submitted to unpaired t-tests. Of these components, only two were significantly different between murderers and the control group.

A parietal component, the fourth principal component, explained 9.38% of variance in the sample and aligned with coherence between posterior sites. The first group of murderers scored higher on this component ($Mx = .21$, $SDx = .96$) compared to the comparison group ($Mx = -.43$, $SDx = .96$), $t(67) = -1.11$, $p < .01$. This component was nearly identical in structure to the third component between the second group of murderers and the comparison group (11.90% variance explained). The second group of murderers scored higher ($Mx = .32$, $SDx = 1.05$) than the comparison group on this component ($Mx = -.33$, $SDx = .83$), $t(45) = 2.39$, $p < .021$. Figure 3 depicts the structure of coherence across sites in these two components.

A left parietal to frontal component, the eighth principal component, explained 4.64% of the variance. This component aligned with coherence between Pz, P3 and a variety of frontal sites. The first group of murderers scored higher on this component ($Mx = .21$, $SDx = .76$) than the comparison group scored ($Mx = -.43$, $SDx = 1.26$), $t(67) = 2.69$, $p < .009$. This component was nearly identical in structure to the fourth component between the second group of murderers and the comparison

FIGURE 3. Overlap of significant coherence differences in both groups of murderers and the comparison group on sites in the posterior region. These components explained 9.38% of variance between the first group of murderers and the comparison group and 11.90% of the variance between the second group of murderers and the comparison group.



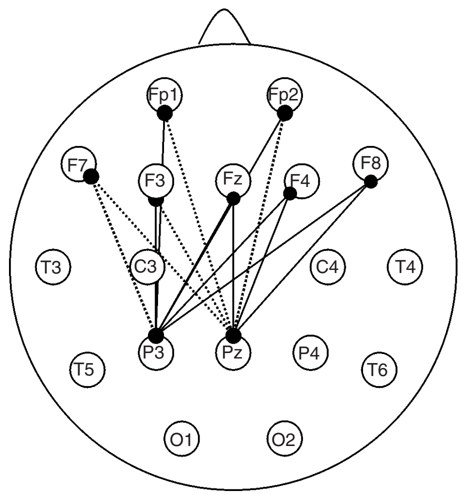
group (8.67% variance explained). The second group of murderers scored higher (*Mx* = .31, *SDx* = .94) than the comparison group scored on this component (*Mx* = −.32, *SDx* = .98), $t(45) = 2.25$, $p < .03$. Figure 4 depicts the structure of coherence across sites in these two components.

As shown in Figure 4, negative correlations between time spent on death row for a subset of inmates (n = 26) and coherence existed between some frontal and parietal sites (F1-Pz, $r = -.41$, $p = .04$; F7-Pz, $r = -.50$, $p = .01$; F3-Pz, $r = -.42$, $p = .03$; F2-Pz, $r = -.34$, $p = .05$; F7-P3, $r = -.36$, $p = .03$).

DISCUSSION

This study identified a pattern of suppressed EEG activity in murderers across the entire EEG spectrum in comparison to matched controls. This pattern was particularly marked in anterior regions. Additionally, individuals on death row exhibited increased coherence among certain distal sites and within some posterior regions as compared to controls.

FIGURE 4. Overlap of significant differences in both groups of murderers and the comparison group on the principal component loading on regions between left parietal sites and frontal sites. These components explained 4.64% of the variance between the first group of murderers and the comparison group and 8.67% of the variance between the second group of murderers and the comparison groups. Dotted lines indicate significant negative correlations between time spent on death row for a subset of inmates (n=26) and coherence (F1-Pz, $r = -.41$, $p = .04$; F7-Pz, $r = -.50$, $p = .01$; F3-Pz, $r = -.42$, $p = .03$; F2-Pz, $r = -.34$, $p = .05$; F7-P3, $r = -.36$, $p = .03$).



Both groups of murderers exhibited less high theta than matched controls in frontal (Fz, F3, F4) and parietal (Pz, P3, P4) regions. As time served on death row is reportedly correlated with cognitive impairment, this finding was hypothesized. This effect was localized primarily to frontal regions, suggesting that this high-theta may be frontal midline theta. A suppression of frontal midline theta would support inmates' self-reported decline in cognitive abilities and attention, and perhaps particularly their self-reported memory impairment.

Both murderer groups exhibited less low alpha than the matched control group in frontal (Fp1, Fp2, F3, F4) and central (Cz, C4) regions; this countered what was expected. It was hypothesized that these individuals would generate more low alpha compared to controls, as inmates have been found to report drowsiness, listlessness, and mental slowness. If there was suppression of low alpha, it may be a carryover from the high-theta band or may be in reaction to generalized arousal. It also may be related to the overall suppression of EEG that has been reported in studies of mental decline with aging (Edman, Brunovsky, Sjögren, Wallin, & Matousek, 2003).

We expected that individuals on death row would have less high alpha as compared to controls, as they often have cognitive impairments which we speculated are most likely associated with changes in their ability to maintain attention. In both groups of murderers, mean magnitude of high alpha was suppressed in the frontal lobes as compared to controls. We hypothesized that both beta-13 and beta-16 would be suppressed in murderers as compared to matched controls. In beta-13 at C3, C4 there was a trend towards this pattern in group 1, and in group 2 this trend reached significance. The suppression of beta-16 was only significant in Group 2.

The finding of suppression of waveforms, particularly in the frontal regions, supports findings in PET research (Raine et al., 1997; Raine et al., 1998). As frontal regions are often damaged in closed head injuries (Richardson, 1990), it was not surprising to find abnormal EEG patterns in these individuals. However, since these groups were compared to a matched control group with neurological impairments, the presence of injury would not explain this overall difference.

The frontal lobes are involved in behavioral inhibition, judgment, self-monitoring, advance planning, and cognitive flexibility (Kolb & Wishaw, 1995). This suggests that frontal lobe differences in the murderers may have put these individuals at risk for engaging in violent, unlawful behaviors. This risk may be increased with a comorbidity of child abuse, serious mental illness, or substance abuse (Nestor, 1992). One or more of these factors is commonly found in the histories of convicted murderers (Raine et al., 1994; Raine et al., 1998).

The overall suppression of EEG waveforms in the murderers, which was significant in all bands in Group 2 and significant in most bands of EEG in Group 1, is similar to studies of elderly patients with brain abnormalities (Salokangas, Loikkanen, & Santala, 1990). Given the stressful experience of living on death rows and the research suggesting that extreme stress increases cognitive aging (Shanan & Shahar, 1983), this finding was not unexpected. To pursue this issue further, correlations were calculated between the EEG variables involved in this study and the actual time on death row. The latter information was available for a subset of 26 individuals from the murderers. There were only two significant correlations. Time spent on death row was correlated with more low theta in posterior regions. However, time spent on death row was not correlated significantly with EEG in any other band. This may be due to the small size of the group for whom time spent on death row was available. The positive correlation between low theta magnitude in the posterior regions and time spent on death row may provide support for Shanan and Shahar's argument regarding stress and cognitive aging.

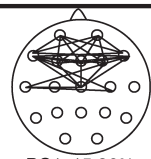
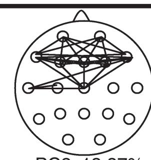
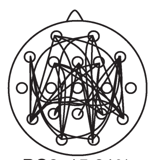
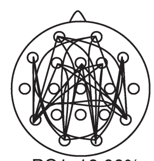
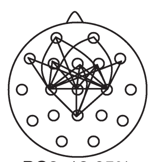
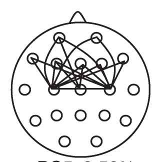
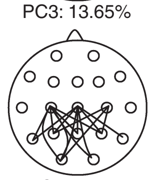
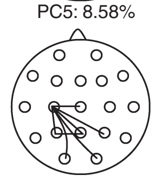
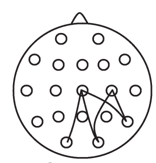
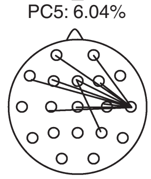
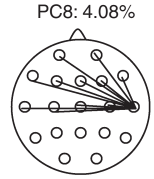
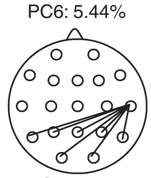
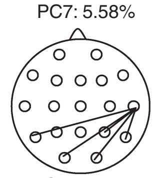
We expected that coherence would be greater in murderers than matched controls, and we found this pattern in both groups. Evans and Park (1997) identified a pattern of abnormally increased coherence in their study of murderers on death rows, and suggested that the increase indicated decreased cortical differentiation as is commonly observed in individuals with a history of brain injury. However, as both groups of murderers in this study showed increased coherence with respect to the neurologically impaired control group it is possible that the observed effect is not due to brain injury alone.

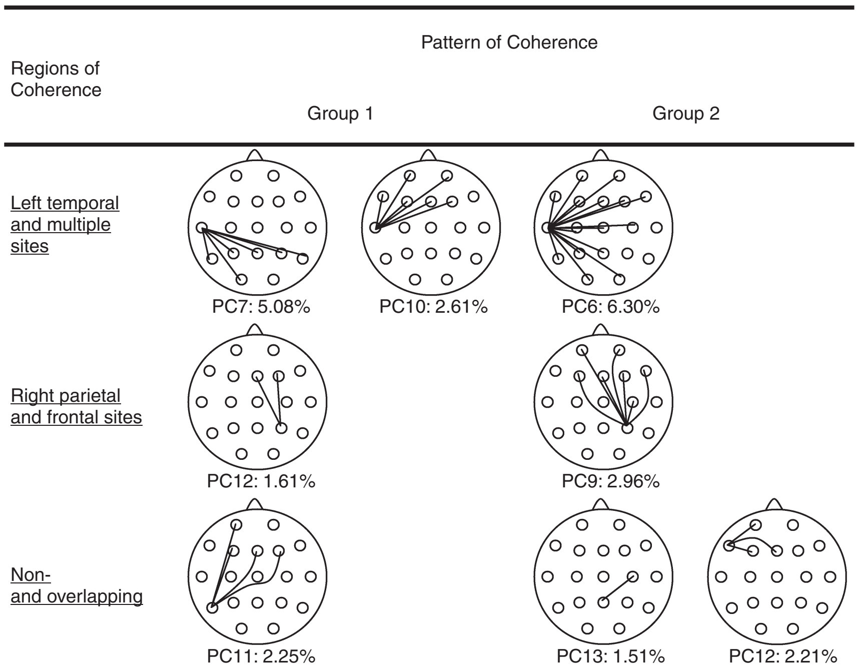
Based on Evans and Park (1997), we hypothesized that individuals on death row would have more impairment between distal cortical regions than matched controls would have. As shown in Figure 4, there was clear evidence of a difference in coherence between distal regions in neurologically impaired controls and murderers in both groups. Between left and central parietal and frontal regions murderers exhibited substantially higher coherence than controls exhibited. However, there was a negative correlation between time spent on death row and coherence between the parietal site and frontal sites such that the longer individuals spent on death row the lower their coherence in these regions. These findings suggest that not all of the differences between the murderers and comparison group can be attributed to time spent on death row.

Unexpectedly, murderers exhibited greater posterior intrahemispheric coherence among several sites compared to matched controls. This finding has been associated in the literature with a decrease in alertness in individuals with brain abnormalities (Edman et al., 2003), and may be related to inmates' reports of listlessness and decreases in alertness.

We expected murderers would have more right than left hemisphere abnormalities of coherence. We did not replicate this finding from Evans and Park (1997). However, that study compared murderers with brain damage to a normative database. In the current study we attempted to contrast murderers with matched neurologically impaired controls. In this study, the principal components analysis revealed a pattern of coherence across all groups between the right temporal regions and frontal regions (see Figure 5, right temporal and anterior sites) which may be the pattern of coherence identified in the study by Evans

FIGURE 5. Overlapping regions of coherence that did not distinguish between two groups of murderers and the matched control group ranked by percent of variance explained.

Regions of Coherence	Pattern of Coherence		
	Group 1	Group 2	
Frontal and left, middle central	 PC1: 15.86%	 PC2: 13.87%	
Occipital, posterior temportal, and frontal electrodes	 PC2: 15.21%	 PC1: 16.00%	
Central and frontal electrodes	 PC3: 13.65%	 PC5: 8.58%	
Central, parietal and occipital electrodes	 PC5: 6.04%	 PC8: 4.08%	 PC11: 2.81%
Right temporal and anterior sites	 PC6: 5.44%	 PC7: 5.58%	
Right temporal and posterior sites	 PC9: 3.96%	 PC10: 2.93%	



and Park (1997). In the earlier study, they may have identified a pattern of coherence that generally is associated with brain injury rather than more specifically with violent behavior.

This study had several limitations. The majority of inmates were selected for QEEG assessment due to independent evidence of factors in their background which put them at risk for brain damage, so care must be taken when generalizing to the death row population at large. Overall, the power spectrum in Group 2 was significantly smaller than either the control group or Group 1. Statistical testing did not identify any outliers, but it is possible that one or more anomalous cases swayed the final results. Additionally, the subset of individuals for whom time spent on death row was available was quite small ($n = 26$); a replication of this study with a larger sample size would be valuable.

Although the use of the neurologically impaired matched controls with no history of violent behavior has been suggested by several studies, it would be useful to conduct a study comparing murderers to both an average population and to matched neurologically impaired controls. A study in which murderers are compared to matched neurologically impaired controls with a history of substance abuse or abuse as children, but no history of violence would also add to this literature.

In conclusion, this study identified a pattern of suppressed EEG activity in murderers in comparison to matched controls. This pattern was particularly marked in anterior regions. Additionally, individuals on death row revealed a pattern of increased coherence among distal sites and within the posterior regions. In combination, these results suggest that murderers experience less cortical differentiation and lower levels of alertness than neurological impaired matched controls experience. Additionally, there were certain other changes in their EEG spectrum and coherences that support murderers' frequently self-reported symptoms of cognitive and physical decline. Some of the group differences were unrelated to time spent on death row. This suggests that the changes in their EEGs can be attributed to factors that occurred before they spent time on death row, as well as factors associated with spending time on death row. Any future study of EEG should address this important issue. Although it may be impossible to completely tease apart the contributions of history, brain injury, and experience on death row, there is evidence that each of these factors contributes to the overall pattern of QEEG findings in these individuals.

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