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EEG abnormalities in psychopath and non-psychopath violent offenders

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ABSTRACT

Previous EEG studies attempted to examine violent behavior as homogeneous construct. Up to date, there is no other research studying Low-Resolution Brain Electromagnetic Tomography (LORETA) technique in psychopath offenders.

Objective: To find electrophysiological differences specifically related to the psychopathy construct and independent of the violent behavior. The current investigation compares the QEEG and the current source density measures of violent psychopath offenders to a non-psychopath violent group.

Methods: The resting EEG activity and LORETA for the EEG spectral fast bands were evaluated in 58 violent offenders, 31 with and 27 without psychopathy according to the Hare Psychopathy Checklist – Revised. All subjects were assessed using the DSM IV-R criteria. The EEG visual inspection characteristics and the use of frequency domain quantitative analysis techniques (Narrow band spectral parameters) are described.

Results: QEEG analysis showed a pattern of excess of beta activity on the left parieto-temporal regions and bilateral occipital areas and decrease of alpha band on the left centro-temporal and parieto-central derivations in the psychopath group. LORETA signified an increase of beta activity (17.18 Hz) in psychopath group relative to a non- psychopath group within fronto-temporo-limbic regions.

Conclusions: These findings indicate that QEEG analysis and techniques of source localization may reveal differences in brain electrical activity among offenders with psychopathy, which was not obvious to visual inspection. Taken together, these results suggest that abnormalities in a fronto-temporo-limbic network play a relevant role in the neurobiological basis of psychopathy.

1. Introduction

Psychopathy is a personality disorder with typical features in terms of antisocial behavior and the Central Nervous System (CNS) functioning. These characteristics include interpersonal and affective traits such as glibness, lack of empathy, guilt or remorse, shallow affect and irresponsibility, as well as behavioral characteristics, such as impulsivity, poor behavioral control and promiscuity. Despite its widespread use as a psychiatric term, psychopathy is not similar to the diagnosis of Antisocial Personality Disorder or Conduct Disorder (American Psychiatric Association, DSM IV-R, 2000)[1] or Dissocial Personality Disorder (ICD-10, 1990),[2] but represents a refinement of these diagnoses. In contrast to these diagnoses, this pathology is defined by not only antisocial behavior but also emotional impairment such as lack of guilt. Only one third of the subjects diagnosed with ASPD meet the criteria for psychopathy.[3] Moreover, psychopathy, unlike ASPD, is a relatively strong predictor of general and violent recidivism.[4]

It has been hypothesized that deficits in the fronto-temporal brain regions, particularly within the network stretching from the orbital frontal cortex to the posterior cingulate cortex, could play relevant roles in the genesis of psychopathy. Dysfunctions in this network have been associated with impairment to social functioning and lack a moral sense.[5]

There are other main theories to explain psychopathy, the Somatic Marker hypothesis of Damasio[6] and the Violence Inhibition mechanism model proposed by Blair.[7] The first hypothesis suggest that prefrontal damage leads to impaired decision-making abilities,

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reflecting an incapability to active autonomic somatic states coupled with the anticipation of reward and punishment. The Violence Inhibition Mechanism model emphasizes the role of empathy for moral socialization. This model suggests that a deficit within, or a failure to develop, this mechanism might, under certain social conditions, result in the development of psychopathic behavior; the individual without this mechanism would not inhibit his or her behavior subsequent to a victim displaying distress cues. The key neurobiological equivalent of this theory is the amygdala.

In our previously reported study of EEG in violent ASPD offenders,[8] we described a certain pattern of EEG abnormalities when compared with non-ASPD offenders using as controls. We postulated that due to the intrinsic heterogeneity of this diagnosis, the EEG abnormalities observed should be different depending on the studied ASPD sample.[8] Based on these findings, together with results from others studies relate with violent subjects,[9–12] and consider that psychopath subjects constitute a conceptually homogeneous group[1,13,14] we hypothesized that alterations in the spectral power of the EEG and current density source analysis during the rest condition would differ between offenders with and without psychopathy. We also examined whether the QEEG abnormalities are associated differentially with traits of psychopathy assessed by PCL-R scale.

2. Materials and methods

2.1. Subjects

The final sample used in this study included 58 violent male offenders, mean age was 29.8 years (SD = 8.09) from a prison located in Havana City, serving sentences for committing violent criminal acts (homicides or murders). Assessment was conducted during a 2 year period, from January 2004 to December 2005.

The psychiatric assessment was made using the clinical and institutional files of all subjects, which included personal history, education, drug use, mental status, and results of the structured clinical interviews performed by trained psychiatrists. All offenders scored within the range of normal intelligence, measured by the Wechsler Adult Intelligence Scale-Revised (WAIS-R).[15] The mean duration of formal education was 9.25 years.

To carry out the psychopathic characteristics evaluation, the PCL-R[16] was used. The experimental group comprised 31 psychopath male offenders according to the PCL-R criteria (cut off point = 30). The control group consisted of 27 non-psychopath violent male offenders.

Socio-biographical, criminological, medical, and psychopathological information was recorded on a standardized score sheet and entered into a computer system for further processing. Characterizations of the sample studied were completed using multiples sources of information, including reports from multidisciplinary teams, family members, neighbors clinical assessment by a psychiatrist, psychologist and a neurophysiology specialist, and criminal files. Inclusion criteria were the absence of current or previous history of neurological or psychiatric abnormalities other than the ASPD or psychopathy diagnosis that may influence the EEG recordings and the imprisonment time that had to be less than a year so that the prison's violent environment did not influence the subject's behavior.

Information relating to drug/alcohol was also obtained. The substances use frequency (alcohol and illicit drugs) was obtained using a customized substance use questionnaire. The category, alcohol use, included those subjects that reported ever drinking alcohol more than once per week during a period of three month. Consumption of any illicit drugs at least once was the selected criteria as positive to use of illicit drugs. Patients presenting concurrent alcohol or any other drug addictions were not included in the study. During our research no offenders had access to alcohol and illicit drugs, because the use of these substances by prisoners is difficult in Cuban prisons. The subjects were not under medication at the time of the test. Fifty five (30 psychopaths) offenders were victims of any type of childhood maltreatment (Table 1).

Participation in the assessment process was voluntary; all subjects signed an informed consent form prior to the study. Data of 65 offenders (9 psychopaths and 56 non psychopaths) with history of head trauma were excluded from the study after finishing all evaluations. 18 additional offenders opted to withdraw from the study after their participation had begun. The study was approved by the Ethics Committee of the Cuban Centre of Neurosciences.

2.2. EEG procedure

EEGs were recorded using a 21-channel MEDICID V EEG system (Neuronic S.A., Havana). Surface electrodes were placed at 19 sites of the International 10-20 system[17] (Fp1, Fp2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, O1 and O2), and referenced to linked earlobes. Electrodes impedance was equal or less than 5 kΩ. The signals were amplified by a factor of 1000 and filtered between 0.05 and 30 Hz. The EEG was continuously recorded (200-Hz sampling rate). The EEG was recorded in a temperature and noise controlled room while the participant was lying on a bed. All individuals were asked to relax and remain at rest during the test in order to minimize artifacts produced by movements, and also to avoid excessive blinking.

Each resting EEG was obtained during eight to 10 min with closed eyes. Subsequently, 2 min of alternation between closed and opened eyes, following 3 min carrying out hyperventilation, and then 2 min of recovery were also recorded. Taking into account that sleepiness could have caused an enhancement of theta activity, the individual vigilance level was checked during EEG acquisition, seeking for slowing of the EEG background activity or for the appearance of typical sleep patterns. In addition, at the end of the recording process, individuals were asked about whether they were awake during the whole recording.

2.3. Visual assessment of the EEG

Several bipolar montages were used for off line EEG interpretation. The EEG was considered normal if it had adequate organization of the background activity (according to the individual age), a well defined spatial differentiation, rhythmic alpha activity and absence of slow or paroxysmal activity.[18] Slow EEG activity was defined as the presence of persistent nonrhythmic theta-delta slow waves. Paroxysmal EEG activity included spikes, sharp waves, and spike and slow wave complexes. EEGs presenting both types of previously described abnormalities were included in the slow and paroxysmal category. Ratios and percentages in all categories were calculated.

Table 1
Comparison between the psychopathic and the control groups on demographic, environmental and behavioral variables.

Variable	Psychopath	Non psychopaths	Statistic
Age	28.3 (7.1)	31.3(8.8)	$F = 2.3$
Years of education	8.6 (1.8)	9.9 (2.0)	$F = 7.6$[a]
PCL-R score	33.6 (2.1)	17.3 (8.1)	$X^2 = 0.0$[a]
Alcohol consumption	26	20	$X^2 = 0.4$
Marijuana consumption	5	6	$X^2 = 0.6$
Psychotropic drugs	10	4	$X^2 = 0.1$
Childhood maltreatment	30	25	$X^2 = 0.5$

[a] Anova or Pearson X^2, $p < 0.05$.

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2.4. Quantitative EEG analysis

Selection of EEG segments for QEEG analysis was done by visual inspection, and segments containing artifact (i.e. eye movements, eye blinks, muscle activity, or other artifacts) were excluded. For this reason, it was only possible to obtain 20–24 closed eyes state segments (without artifact) of 2.56 s from each individual for quantitative EEG analysis. The exact number of segments depended on how cooperative the individual was, getting a minimum of 20 required for the study entry. One minute of artifact-free EEG is considered the minimum amount of EEG required to obtain reliable quantitative measures.[19,20] Fast Fourier Transform (FFT) was applied in order to obtain the cross spectral matrixes of all individual records,[19] which were calculated with a spectral resolution of 0.39 Hz, from 0.78 to 19.53 Hz.

Quantitative measures were log-transformed (i.e., $X' = \log_{10}X$ for absolute power and mean frequency; $X' = \log[X/(1.0-X)]$ for relative power) to acquire Gaussianity (i.e., to obtain a normal distribution). Physiological measures do not frequently present a normal distribution, which may increase the probability of Type I (false positive) and Type II (false negative) errors. Log-transform alters the raw data distribution (i.e., normalizing), without changing the relationship between the scores. This improves the specificity and sensitivity of the quantitative analysis. All spectral measures were obtained for referential (linked earlobes) data, and transformed using Z −scores (the values of the normative Cuba database, see the statistics section for database details).

2.5. EEG source estimation

The Low-Resolution Electromagnetic Tomography (LORETA)[21] was used to compute, from the scalp-recorded electric potential distribution, the three-dimensional distribution of electrical activity (i.e., the current density) produced by neuronal generators within a three-shell spherical head model. The head model includes scalp, skull, and brain compartment. The brain compartment was coregistered to the Talairach probability brain atlas, digitized at the Brain Imaging Center of the Montreal Neurological Institute and consisted of 2394 voxels at 7 mm spatial resolution. The LORETA functional images represent the electrical activity at each voxel as squared magnitude (i.e., power) of computed current density.

Using the Neuronic QEEG analysis software (Neuronic S.A.), selected EEG frequency range (alpha and beta bands) was saved in a "text" format to be read later on through a specific software system developed for this purpose. Current density vectors (CD) were calculated for each individual from all the data segments using the Neuronic Source Localizer software (Neuronic S.A.). This program provided a spatially restricted solution to cortical gray matter and basal ganglia in the Talairach Human Brain Atlas.

2.6. Statistical analysis

Pearson Chi square test and one way ANOVA test were used to compare demographic, environmental and behavioral variables (Statistic 6.0 for Windows). The level of statistical significance was set at 0.05 for all the tests.

2.6.1. QEEG analysis

2.6.1.1. Spectrum. The mean of EEG cross spectral parameters for both psychopath and non-psychopath groups were compared with the Cuban normative database using the Z transform.[22] This normative database was constructed from the EEG of 211 normal subjects' (105 males, 106 females) with an age range from 5 to 97 years. Normative coefficients were obtained by carrying out a polynomial regression with age of each log spectral value. Normalized values, expressed as the number of standard deviations from the mean of the norm, were calculated for every frequency and electrode and stored as a "Z spectrum".[22] Factors such as age might affect EEG data by increasing inter-individual variability.[23] The use of normalized values for statistical analysis eliminates these effects that, otherwise, should have been taken into account for comparisons between the groups.

2.6.2. Statistical methodology to compare the Z spectra mean of both groups

In order to evaluate differences between the Z spectra of both groups, a permutation test was used.[24–27] The permutation test has the following advantages: free distribution -which controls the experiment wise error for simultaneous univariate comparisons. No assumption of an underlying correlation structure, - Providing exact *p*-values for any number of individuals, frequency points and recording sites.

The *t* statistics and max (*t*) were calculated. Max (*t*) represented the maximum of t statistic in each electrode, and frequency.

Multivariate statistics can be used to summarize and test differences between two Z spectra obtained from the maximum value of all the univariate statistics.

2.6.3. These statistics were obtained as follows

Step 1: The observations were repeatedly permutated between groups. Both statistics were calculated for every repetition.

Step 2: The distribution was estimated using the statistics calculated in the step above.

Step 3: Significance levels was set using the t and max(*t*) of the original samples with the distribution estimated in Step 2.[24–27]

2.6.4. Inverse solution analysis

In order to identify significant regional differences between groups in current density (CD) for beta and alpha EEG bands, a *t*-test for independent samples with correction for multiple comparisons was performed (Neuronic Statistica software, Neuronic S.A.). The final outcome was a map of the *t*-test values for each voxel thresholded at a false discovery rate (FDR) $q = 0.1$. Coordinates of main activation are represented in Talairach space (Neuronic Tomographic Viewer, Neuronic S.A.).

2.6.5. Correlation analysis

Using Pearson's correlation analysis we evaluated the association among PCL-R traits, the total PCL-R scores, electrodes and EEG frequencies. To carry out this analysis we used the sites where there was a significant difference between these groups. An alpha level of 0.05, was used as the statistical significance level and $q = 0.1$ (after the false discovery rate correction for multiple comparisons, FDR).

3. Results

3.1. Demographic and behavioral results

Analyses of demographic data indicated no significant differences in age between the two groups (Table 1). Scores for PCL-R and years of education showed significant group differences. Marijuana and alcohol use, psychotropic medication consumption and antecedent of childhood maltreatment did not show significant group differences (Table 1).

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Table 2
EEG visual inspection results in both groups.

Group	Normal	Slow	Paroxysmal	Slow and paroxysmal
Psychopath	6 (19.35%)	13 (41.93%)	5 (16.13%)	7 (22.58%)
Non-psychopath	6 (22.22%)	9 (33.33%)	3 (11.11%)	9 (33.33%)

3.2. Visual inspection

The rest EEG visual analyses revealed that 27 offenders (21.95%) had background activity disorganization, with medium voltage range amplitude and alpha rhythm attenuation, sometimes barely incipient. Fourteen (51.9%) of them met the psychopath criteria.

Table 2 presents details of the EEG visual analysis results. In this analysis both group's (Psychopaths and Non psychopaths) results were very similar. SLOW EEG was the category including the highest number of subjects (around 37.9%), followed by SLOW and PAROXYSMAL EEG category (27.6%). Twenty (20) subjects from both groups were included in the other two categories. The Pearson Chi square test comparison found no significant differences between the two groups regarding the presence of EEG abnormalities by visual inspection ($X^2 = 1.20$, df = 3, $p = 0.75$).

Table 3 shows the topographical distribution of the EEG abnormalities found in both groups. Widespread was the most frequently found localization for the EEG abnormalities. A Pearson Chi square comparison was carried out only taking into consideration the SLOW category and comparing temporal and widespread localizations. There were no group differences between these topographical distributions regarding the slow EEG activity ($X^2 = 1.64$, df = 1, $p = 0.20$).

3.3. Quantitative EEG analysis

Significant statistical differences between the mean parameters of cross spectral measures of Psychopaths and Non-psychopath groups using the permutation test were found in the beta band within a frequency range of 17.19–18.75 Hz at right occipital region and left posterior temporal-parietal and occipital areas. The power value for this frequency was increased for the Psychopath group. In contrast, within the 9.37–11.72 Hz frequency range of the alpha band a decrease of the energy was found) at the left central-temporal regions and the parietal lead for this same group.

3.4. Correlation between EEG frequencies (QEEG) and traits of PCL-R scale

Significant negative correlations were found between the shallow affect ($r = -0.23$; $p < 0.01$), failure to accept responsibility for own actions ($r = -0.23$; $p < 0.01$) and F1 factor of the PCL-R scale ($r = -0.18$; $p < 0.04$) with the alpha energy level at left central region (Table 4).

Significant correlation was found on the left temporal area (many short-marital relationships and alpha activity) ($r = -0.20$; $p < 0.02$).

The beta activity for the left parietal-occipital regions was positively correlated with glibness/superficial charm ($r = -0.20$; $p < 0.03$). The failure to accept responsibility for one's own actions showed positive correlation ($r = 0.20$; $p < 0.25$) at this same area (Table 4). Beta activity in the left posterior temporal region revealed negative correlation with the glibness/superficial charm ($r = -0.23$; $p < 0.01$) (Table 4).

Table 4
Correlation coefficients between EEG frequency bands and the items, total score, F1 and F2 factors of PCL-R scale.

Hare scale traits	Alfa			Beta			
	C3	T3	Pz	P3	T5	O1	O2
1) Glibness/superficial charm	–	–	–	0.20	−0.23	0.17	–
1) Grandiose sense of self-worth	–	–	–	–	–	–	–
1) Need for stimulation/proneness to boredom	–	–	–	–	–	–	–
1) Pathological lying	–	–	–	–	–	–	–
1) Conning/manipulative	–	–	–	–	–	–	–
1) Lack of remorse or guilty	–	–	–	–	–	–	–
1) Shallow affect	−0.23	–	–	–	–	–	–
1) Callous/lack of empathy	–	–	–	–	–	–	–
1) Parasitic lifestyle	–	–	–	–	–	–	–
1) Poor behavioral controls	–	–	–	–	–	–	–
1) Promiscuous sexual behavior	–	–	–	–	–	–	–
1) Early behavior problems	–	–	–	–	–	–	–
1) Lack of realistic, long-term goals	–	–	–	–	–	–	–
1) Impulsivity	–	–	–	–	–	–	–
1) Irresponsibility	–	–	–	–	–	–	–
1) Failure to accept responsibility for own actions	−0.22	–	–	−0.20	–	–	–
1) Many short-term marital relationships	−0.20	–	–	–	–	–	–
1) Juvenile delinquency	–	–	–	–	–	–	–
1) Revocation of conditional release	–	–	–	–	–	–	–
1) Criminal versatility	–	–	–	–	–	–	–
Total HARE	–	–	–	–	–	–	–
F1	−0.019	–	–	–	–	–	–
F2	–	–	–	–	–	–	–

The evaluated sites and frequencies where the ones showing significant differences in the permutation test between groups $p < 0.05$, $q = 0.01$.

3.5. EEG source analysis

3.5.1. Comparison of activity sources (LORETA) between both groups studied

LORETA source imaging revealed a significant increase of beta activity at 17.18 Hz on the following Brodmann's areas: 11, 12 (orbitofrontal cortex); 8 (superior frontal gyrus); 4, 43 (rolandic operculum); 6 (supplementary motor area); 13 (insula); 11 (rectus); 23, 32, 33 (cingulate gyrus); 38 (superior temporal pole); 39 (angular gyrus); 40 (supramarginal); 31 (precuneus); 7 (inferior parietal lobule) and caudate in both hemispheres; 44 (opercular portions of the inferior frontal gyrus); 7 (postcentral area); 22 (superior temporal gyrus); 21 (medial temporal gyrus) in the left hemisphere and 41, 42 (heschl gyrus) in the right hemisphere in the psychopath group when they were compared with non-psychopath offenders ($p < 0.05$ after false discovery rate correction for multiple comparisons; Fig. 1).

There were no other significant group differences in any other band.

Table 3
Topographic distribution of EEG abnormalities.

Group	Slow				Paroxysmal			Slow and paroxysmal		
	Frontal	Temporal	Parietal	Widespread	Frontal	Temporal	Parietal	Frontal	Temporal	Widespread
Psychopath	0 (0%)	3(9.68%)	0(0%)	10(32.26%)	4(12.90%)	1(3.22%)	0(0%)	2(6.45%)	2(6.45%)	3(9.68%)
Non-psychopath	0 (0%)	0 (0%)	3 (11.11%)	6 (22.22%)	1 (3.70%)	1(3.70%)	1(3.70%)	2(7.41%)	0(0%)	8(29.63%)

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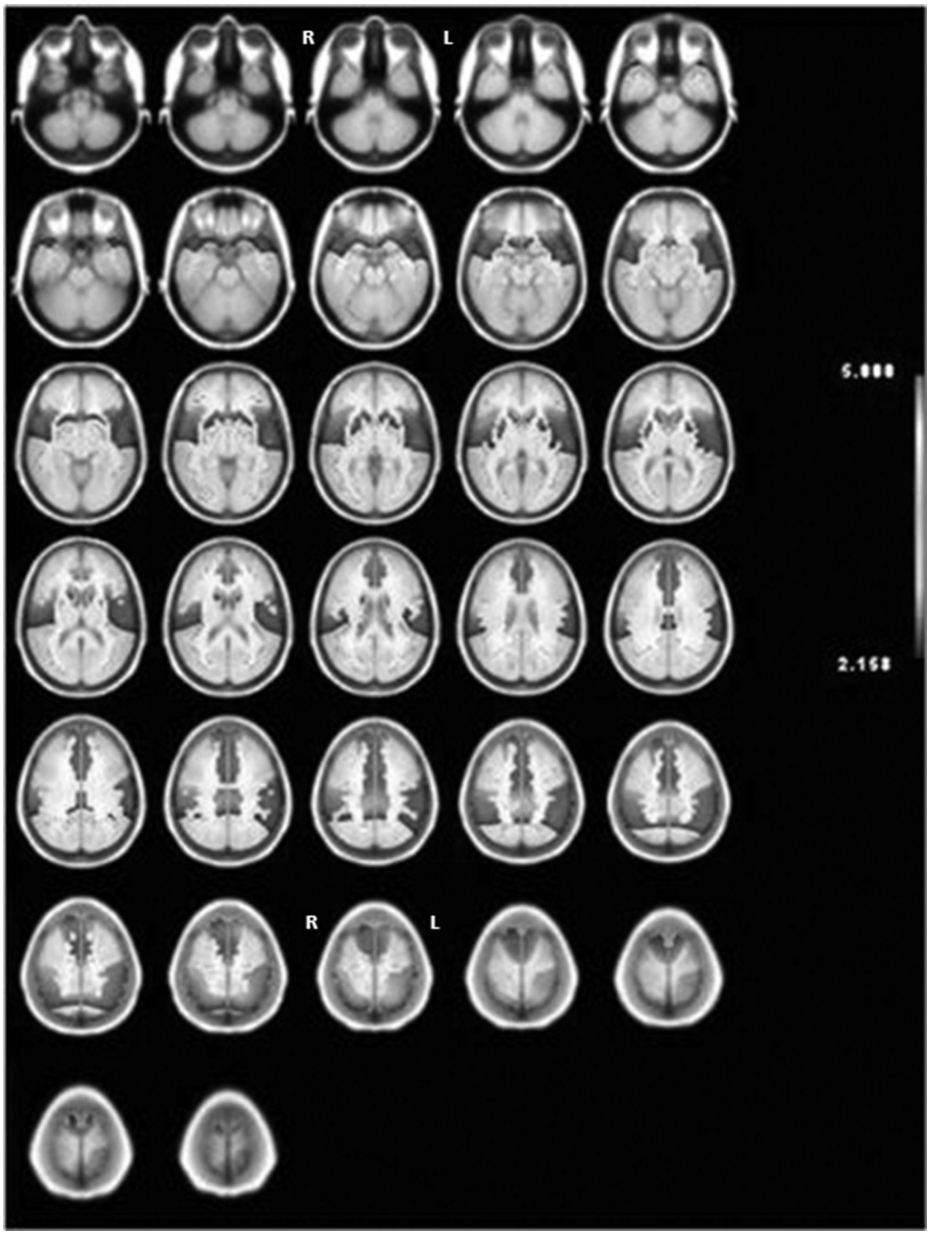

Fig. 1. Anatomical distribution of maximum t values between Psychopath and Non-psychopath groups (p-value: 0.05, corrected for multiple comparisons using FDR). Comparison between psychopath and non-psychopath groups using t of student (independent samples) showed the highest significant differences on a broad region within both hemispheres, mainly orbitofrontal cortex, superior frontal gyrus, rolandic operculum; supplementary motor area; insula; rectus; cingulate gyrus; superior temporal pole; angular gyrus; supramarginal; precuneus; inferior parietal lobule and caudate in both hemispheres; opercular portions of the inferior frontal gyrus; postcentral area; superior temporal gyrus; medial temporal gyrus in the left hemisphere andheschl gyrus in the right hemisphere in the psychopath group. All t statistics are positive and displayed in black (the mean of the psychopath group is greater than the mean of the non-psychopath group). R right hemisphere; L left hemisphere.

4. Discussion

In the present study, the widespread slow wave presence was the most frequently found localization and abnormality through EEG visual inspection. Also, background activity disorganization was found in subjects from both groups. There were no statistical differences between the Experimental and Control groups regarding the presence of EEG abnormalities found or their topographic localization. The EEG studies of criminals and individuals categorized through psychological measures as psychopaths have typically found a slow activity increase in qualitative EEG assessment.[10,28]

Significant differences in QEEG and regional current source density between psychopath and non-psychopath groups were found. The psychopath group had more beta energy in the left temporo-parieto-occipital and right occipital regions and less alpha activity in the left central-temporal and parieto-central areas than the Control group. LORETA showed differences especially in the frontal and the temporal cortex.

Increase of beta activity and decrease of alpha power were found in psychopath group when QEEG results were compared with the control group. Similar findings has been demonstrated in subjects with moderate intermittent explosive disorder (mIED),[11] in impulsive subjects,[12] and in children with attention deficit/hyperactivity disorder (AD/HD).[29,30] These two types of psychiatric disorders are considered important precursors of psychopathy.[31] Our results confirm that this EEG pattern could be related with

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a more broad-spectrum of behavior disorders, characterized by an increased tendency for impulsive action and behavioral disinhibition.

Beta activity is believed to result from cortical/cortical and thalamo/cortical interactions,[32] and increased beta may indicate cortical hyperarousal.[33] However, physiological underarousal is a one of the theories for explaining the expression of aggressive and violent behavior,[34–38] the opposite physiological pattern had been described in some researches with psychopath subjects[39,40] and in hostile men.[41,42] Our findings could potentially be interpreted as evidence of cortical disinhibition in this psychopath group as compared to non psychopaths.

Decrease alpha activity in psychopath offenders had been associated to a failure in functional cortical development (maturational retardation hypothesis).[43] This finding is consistent with researches that demonstrate less alpha activity levels in subjects with antisocial behavior.[36,44,45] α rhythm is the normal rhythm seen in a subject who is awake with his eyes closed. It is maximal over the occipital and, to a lesser extent, the parietal regions, and is often less evident over the dominant hemisphere. The adult pattern of dominant α rhythm described above becomes evident in late adolescence and is referred to as the mature EEG.[46] Nevertheless, by the age range of subject studied, we consider that this finding supports the presence of Central Nervous System abnormalities in psychopath offenders.

High beta power has been observed in subjects with chronic alcoholism even after months of abstinence.[47] The alcohol use was one of the controlled variables in this study. However, given the evidence of the increased beta activity in alcoholic subjects, we should not ignore the effect of this substance, at least partly, in our findings. A recent research had showed an association between duration of marijuana use and reduction in alpha and beta power at posterior electrode locations.[48] Due to marijuana being the illicit drug most referred to the subjects in our sample; it is difficult to rule out its effects on EEG findings, mainly in alpha power band.

The EEG provides an excellent index of brain activation level, particularly in cortical (as opposed to subcortical) regions.[18] Nevertheless, recent advances in EEG recording technology and EEG analysis methods make the window into the brain much more transparent, and the signal−source relationship has become clearer.[49] On the other hand, the development of more advanced functional brain imaging techniques such as PET and fMRI with the better spatial resolution, had reported reduced metabolism in violent patients in subcortical structures relate with learning and emotional regulation.[5,43,50,51] In order to maximize the values of these techniques to fully understanding the neurophysiologic correlates of psychiatric illness, the most appropriate is the use of structural and functional neuroimaging in conjunction with the advance methodologies of the electrophysiological techniques.

An important finding was that the sources of increase of beta activity in psychopath offenders, using LORETA were localized on the frontal cortex, the temporal cortex and the paralimbic areas. These results support the idea that psychopathic behavior is associated with brain abnormalities in a prefrontal -temporo-limbic circuit − regions that are involved in emotion and learning.[5,43,49] LORETA solves the inverse problem by constraining the electrical neuronal activity to comply with the property of maximal synchronization, i.e., by assuming similar activation among neighboring neuronal sources. A prerequisite to be able to define the inverse solution results within the structural MRI is the co-registration between these two imaging modalities, i.e. the EEG space and the MRI space.[21] This step requires that electrode positions are matched to the scalp surface defined by the MRI using some transformation (rotation and translations) operations. These parameters are usually obtained by measuring some 'common' landmarks during both the EEG as well as the MRI acquisition. Most commonly, MRI-visible markers are placed on the skin that corresponds to the position of the electrodes and/or some fiduciary landmarks (e.g. nasion, inion, pre-auricular points, and vertex). In order to avoid the labor-intensive measurement of the electrodes and fiduciary landmarks on every subject, many studies use one single template MRI (such as the MNI brain from the Montreal Neurological Institute) and assume a standard electrode coordinate system. In this case, pre-defined translation parameters are used to match the EEG to the MRI space. Individual differences in head size and electrode positions are thereby ignored, leading to a limited accuracy with regard to the anatomical precision of the source locations. The use of individual anatomical MRI to calculate sources of localization eliminates these limitations and it contributes to increase the accuracy of LORETA localization as has been demonstrated by different researches.[52,53] LORETA is a technique that facilitates a deeper understanding of the neurological findings present in the EEG.[21] In general, LORETA helped to define the structures related to the increase of beta activity as a sign of a dysfunctional (hyperexcitability) neuronal state, probably secondary to central nervous system injury. To our knowledge, no previous studies of LORETA involving psychopath samples have been published.

Our findings support the hypothesis that fronto-temporal brain areas including cortical and subcortical regions contribute to a paralimbic network that is functionally and structurally altered in psychopaths.[5] Impairments of this system have a significant role in the etiopathogenesis of psychopathy. Frontal cortex impairments in executive cognitive functions involving planning, abstract reasoning, attention, and behavior regulation in response to environmental feedback may increase the risk of aggression by leading to (1) misattributions of threat and hostility in conflict situations, (2) inability to generate socially acceptable solutions in response to anger situations, (3) inability to execute actions that will avoid an argument or aggressive interaction, or (4) poor behavioral control over hostile cognitions and negative affect.[50,51,54,55] Whereas temporal lobe dysfunctions produce symptoms which affect different types of behaviors, like sexuality, visual perceptions, familiar faces recognition, emotional expressions perception, and even religious beliefs. They can also affect personal relationships, "ego" perception with depersonalization and derealization phenomena; in short, behaviors which are essential to the human being.[56,57]

This hypothesis is consistent with other neurobiological perspectives that emphasize the role of frontal cortex in psychopathy,[58] the amygdala dysfunction as clue piece of this disorder,[59–62] and deficiency in the behavioral inhibition system.[63] Our findings are in agreement with a significant neurocognitive model (the Integrated Emotion Systems model, IES) which associates amygdala and prefrontal dysfunctions in the psychopathy genesis.[60] Our research confirms that functional impairment of CNS of psychopathy concern to more than one brain region.

Several neuroimaging studies in psychopaths have revealed reduction of grey matter in the prefrontal cortex and abnormal brain activation in limbic regions, as well as in the prefrontal and temporal lobes.[64–66] A recent study employing diffusion tensor imaging found that psychopathic individuals showed reduced fractional anisotropy of the uncinate fasciculus pathway connecting limbic and ventral frontal brain regions.[67]

Another social factor controlled in our study was childhood maltreatment. In the context of the paralimbic hypothesis in the genesis of psychopathy this aspect should not be ignored. Different researches had reported that such severe early stress and abuse have the potential to alter brain development and origin limbic dysfunction during specific sensitive periods of cortical maturation.[68] There are studies in violent offenders, which related child

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abuse with reduced right hemisphere functioning, mainly in the right temporal region.[68] In our research we did not find significant differences in the childhood maltreatment reports for both violent groups. It is possible that neurobiological impairments caused by this risk factor are more related to violent behavior in general than to psychopathy.

When evaluating the statistical correlations among QEEG and psychopathic traits, Hare total score, F1 and F2 factors, it was demonstrated that important characteristics of psychopaths related with interpersonal and affective feelings have a negative relationship with the decrease of alpha activity at the left centro-temporal regions. F1 factor of PCL-R scale showed negative relation with alpha activity level at left central lead. An alpha deficit could be a correlate of reduced cortical regulation or gating of responses to maladaptive behavioral impulses. The equal mode these correlations could be connected with includes flattened emotional reactions and development of socially inappropriate behaviors typical of psychopaths.

Significant positive correlations were found between the beta activity at the left parieto-occipital regions and important salient traits (traits as glibness/superficial charm and failure to accept responsibility for own actions) within interpersonal and affective areas. Thus, these results are consistent with research demonstrating increase beta power in relation to antisocial behavior.[69] EEG activities in the beta range are considered to be an index of the level of cerebral activation.[33] The present findings could potentially be interpreted as evidence of lack of Central Nervous System inhibition (hyperexcitability) in this psychopath group as compared to controls. The idea that individuals with psychopathic behavior show increased arousal in response to sensory stimuli is reflected in one of the more noteworthy theories of physiological function in this type of subjects.[39,69]

Future EEG work in this area should also explore the gamma band to determine whether there are significant differences in these frequencies between psychopath and non-psychopath offenders. Gamma waves have been associated with cognitive states such as attention, learning, and consciousness.[70] Lower levels of gamma power might hinder the coherent formation of images, thoughts, and memories, as indicated by human and animal research. Gamma waves are also disrupted in patients with ADHD, schizophrenia, and other neurological diseases.[70]

Summarizing, the results of this study support the hypothesis that fronto-temporal brain functions are impaired in psychopaths. QEEG and LORETA results indicate that violent offenders do not constitute a homogeneous group in terms of EEG profile. Both types of EEG assessment could be important tools for the identification of functional abnormalities of CNS in psychopath offenders.

Conflict of interest

None declared.

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Ethical approval

No ethical approval is needed as it is a short report.

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