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Paroxysmal Fast Activity: An Interictal Scalp EEG Marker of Epileptogenesis in Children

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Abstract

Purpose—High frequency oscillations (>100 Hz) have been proposed as localized markers of epileptic networks, but require intracranial electroencephographic (EEG) recordings. This study explored if β - and γ - frequency paroxysmal fast activity (PFA), recorded interictally during non-REM sleep, could be used as a scalp EEG marker of epileptogenesis in children.

Methods—The presence and scalp location of PFA was visually identified in 681 patients with overnight video-EEG (age 0 to 18 years), and compared with ictal onset sites. The clinical features of patients with PFA were compared with patients without PFA along with evidence of PFA evolution in 35 patients who had multiple video-EEG records.

Results—PFA was present in 16% of all patients and in 28% of those with seizures. PFA was more frequently observed in EEGs from patients 3 years of age or younger (>40%), and children with infantile spasms (85%). When present, PFA predicted if the patient had epilepsy with 97% accuracy, and was not found in individuals with non-epileptic events. PFA localized with EEG-ictal onset sites with 91% sensitivity and 82% accuracy. Ictal scalp EEG events began with β - and γ -frequencies in 80% of patients with PFA, and they had increased seizure frequencies compared with non-PFA cases. In patients with multiple video-EEG studies, PFA showed progression over increased numbers of electrodes in 74%, improvement in 15%, and remained unchanged in 12% and correlated with seizure evolution. PFA was not associated with other seizure types, anatomic location, type of antiepileptic drug, etiology, or histopathology.

Conclusions—While relatively infrequent, interictal PFA was specific in identifying younger children with epilepsy, co-localized with the ictal onset sites on scalp video-EEG, and progressed and correlated with seizure severity. We propose that PFA is a scalp EEG marker of epileptic networks with the advantage of being recorded non-invasively during interictal non-REM sleep.

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Keywords

PFA; Lennox-Gastaut; hypsarrythmia; fast ripples; epilepsy; electroencephalography; ictogenesis; West syndrome

Introduction

Pathologic fast (β - and γ -frequency) scalp EEG-events, here termed paroxysmal fast activity (PFA), was first identified in the 1940's and 1950's, and has been described under various names, including fast paroxysmal rhythms, repetitive fast discharges, and beta band seizure pattern (Aird and Zeale 1951; Blume et al. 1973; Gibbs et al. 1943; Halasz et al. 1968; Jasper and Kershman 1949; Rodin et al. 1976). PFA, especially generalized events, have historically been associated with severe epileptic encephalopathy, such as infantile spasms and the Lennox-Gastaut syndrome, and PFA is most often observed during non-REM sleep (Brenner and Atkinson 1982; Gastaut et al. 1966; Green and Wilson 1961; Kobayashi et al. 2004; Lombroso and Erba 1969).

Enthusiasm in using scalp PFA in the diagnostic assessment of patients with seizures has been low because they are reported to occur in less than 4% of EEG records (Halasz et al. 2004; Nealis and Duffy 1978). However, there has been resurged interest in fast and very-fast EEG oscillations as potential surrogate markers in identifying epileptic networks in humans and animal models of epilepsy (Bragin et al. 1999a; Bragin et al. 1999b; Bragin et al. 2002a; Bragin et al. 2002b; Jirsch et al. 2006; Rampp and Stefan 2006; Traub 2003; Traub et al. 2003). These fast EEG oscillations are usually greater than 60 Hz with very high-frequencies above 250 Hz (sometimes referred to as ripples and fast ripples), and because of their frequency and low voltage amplitudes have been difficult to identify because they require use of intracranial electrodes and amplifiers capable of very high EEG-signal sampling rates (Fisher et al. 1992; Worrell et al. 2004). Despite these limitations, high-frequency epileptiform oscillations are proving useful in localizing seizure onset zones in mostly adult patients with mesial temporal (Staba et al. 2004) and neocortical epilepsies (Jirsch et al. 2006). With this background in mind, our goals were to re-evaluate the occurrence and localization of scalp recorded PFA and EEG-ictal onset zones in children. We hypothesized that due to their higher incidence of neocortical epilepsies, more children would show PFA on scalp EEG and the location of these fast frequency oscillations would overlap with EEG-identified ictal onset zones similar to what has recently been observed with higher-frequency EEG oscillations in older patients.

Methods

Patient Population & EEG Acquisition

Inclusion criteria were all patients referred to the Pediatric Epilepsy Program at the University of California, Los Angeles (UCLA) for inpatient overnight video-EEG monitoring from 2001 to 2003. These calendar years were chosen because the video-EEGs were digitally archived, and records were reviewed by the same individuals (JYW and SK) who identified PFA at the time of initial EEG reading using standardized criteria. There

were no exclusion criteria, and if patients had multiple video-EEGs during this period the first record was used in the initial assessment. The clinical purpose of video-EEG included diagnosis of epileptic versus non-epileptic events, determination of seizure classification and epilepsy syndrome, and pre-surgical evaluation. A Grass-Telefactor digital system (West Warwick, RI) utilizing at least 21 gold-plated electrodes placed according to the International 10–20 system was used. Two cheek electrodes (T_1 & T_2 pre-auricular) were added in patients undergoing pre-surgical evaluation. EEG acquisition included a digital sampling rate of 200 Hz, and frequency filters set to capture from 1 to 70 Hz EEG signals (no 60 Hz notch filter). The EEG recording was displayed on a 21 inch CRT monitor and reviewed using Twin 2.6 software program. All patients had a minimum of 24 hours of video-EEG recordings (including natural sleep), and for pre-surgical patients 3 or more typical ictal behavioral events were captured.

Scalp PFA EEG Identification and Classification

Sleep records were chosen because prior literature indicated that PFA was better visualized during non-REM sleep (Brenner and Atkinson 1982). Our own pilot study agreed with this assessment in that PFA was only observed during non-REM sleep in 7 pediatric patients and no PFA was found during awake EEG recordings. On the first night of video-EEG recording and with the patient on the same pre-admission dose of anti-epilepsy drugs (AED; if on medications), a continuous 20 minute segment of non-REM sleep was visually inspected for the presence and scalp electrode location of PFA. Non-REM sleep was defined by vertex waves, K-complexes, and sleep spindles. PFA was defined as paroxysmal EEG events of β (14 to 30 Hz) and γ (> 30 Hz) frequencies, voltage amplitudes greater than background, lasting at least 0.2 seconds (Brenner and Atkinson 1982; Green and Wilson 1961; Halasz et al. 2004) (Fig. 1). Excluded by visual inspection were normal sleep spindles, faster normal sleep K-complexes, muscle artifact, movement artifact, and electrode artifact. PFA at ictal EEG onsets were also excluded (Blume et al 1984). Information regarding ictal onset zones were abstracted from the original EEG report and not studied during the EEG re-review. Electrodes and their associated anatomic regions were classified as follows for both PFA and ictal onset: frontal for Fp1, Fp2, F3, F4; temporal for F7, F8, T1, T2, T3, T4, T5, T6; central for C3, C4; parietal for P3, P4; occipital for O1, O2. If two or more electrodes are equally involved, then both regions would be included, such as frontocentral for F3 C3. PFA and ictal EEG onsets were classified as: Focal if they were found in one consistent region of the scalp EEG whether hemispheric, lobar, or sub-lobar, and did not change location during the recording (Fig. 1A); multifocal if two or more independent areas of the scalp EEG showed PFA or ictal onsets; bilateral if PFA or ictal onsets occurred synchronously in homologous bi-hemispheric regions on scalp EEG (Fig. 2); and generalized if they were present diffusely in nearly all electrodes on both sides of the skull. The rate of PFA occurrence (events per minute), and frequency of oscillations (Hz) within the PFA were not determined.

Patient Analyses

After qualitatively identifying the presence of PFA for each patient, this study characterized PFA clinical features in different phases of analysis. In the first phase, all patients undergoing video-EEG in the 2001 to 2003 calendar years were assessed for the presence or absence of PFA, and this was compared with age at video-EEG. In the next phase, the subset

of patients in the 2001 to 2003 cohort with clinical seizures were assessed to determine if the scalp location of PFA overlapped with EEG-ictal onset zones. To define EEG scalp localization, the head was separated into 10 anatomic regions (frontal, central, temporal, parietal, and occipital; 5 per hemisphere), and the regions were considered positive when that region showed PFA or ictal onsets in the corresponding EEG scalp electrodes as previously described (Wu et al. 2006). The sensitivity [sites with +PFA and +seizure onset / {(+PFA and +seizure onset) + (+ seizure onset but -PFA)}], specificity, [sites with - PFA and -seizure onset / {(- PFA and -seizure onset) + (regions with +PFA but -seizure onset)}], and accuracy [{(regions with +PFA and +seizure onset) + (regions with -PFA and -seizure onset)} / total number of anatomic regions] of PFA localization with EEG ictal onsets were determined.

The next phase was designed to assess the evolution of interictal sleep PFA over time. For this analysis the subset of children with two or more video-EEGs from 2000 to 2004, where one of the telemetries was during 2001 to 2003 calendar years were reviewed. Sleep PFA between multiple video-EEGs were assessed as the same if there were no difference in scalp EEG-anatomic regions between the two studies; improved if PFA between studies occurred over smaller anatomic regions; or progressive if new PFA occurred over larger anatomic regions (either within the same hemisphere or in the opposite hemisphere).

The final phase of patient analysis characterized additional clinical and epilepsy features of patients with PFA. For this portion of the study, patients referred for pre-surgical evaluation with neuroimaging (1.5 T MRI and FDG-PET) during the 2003 calendar year were clinically assessed as previously described (Koh et al. 2005; Mathern et al. 1999). Clinical characteristics were abstracted from the medical record, and included gender, age at the time of video-EEG, seizure type (generalized, partial complex partial, infantile spasms, etc), seizure frequency (events per day), type and number of AEDs at the time of video-EEG, age of seizure onset, seizure duration (defined as time from seizure onset to time of video-EEG), presumed seizure etiology based on neuroimaging findings, and histopathologic diagnosis (for those children who underwent surgery).

Statistical Tests

Patient data was placed into a Microsoft Excel spreadsheet for statistical testing (Stat View 5; SAS Institute, Inc., Cary, NC, USA). Statistical tests included t-tests, ANOVA, and Chi-square where appropriate. Results were considered different at a minimal level of significance of $P < 0.05$.

Results

Clinical Cohort

For calendar year 2001 to 2003, 681 patients had video-EEG studies at UCLA's Pediatric Epilepsy Surgery program. All were 18 years of age or less except 9 patients who were from 19 to 42 years. Most patients were less than age 7 years at the time of video-EEG (mean $\pm$ SD; 6.9 ± 5.5 years; median 6 years; Fig. 3A).

PFA Characteristics

By visual inspection, PFA were EEG events in the fast β and γ frequency range, lasting from 200 milliseconds to 8 seconds, occurring one to >100 times in a 20 minute non-REM sleep period (Figs. 1 and 2). PFA often occurred in association with epileptiform spike and slow wave discharges. The youngest patient with interictal PFA was 6 weeks of age (born full-term) and the oldest was 18 years.

PFA-Low Sensitivity but High Specificity for Patients with Seizures

PFA was present in 106 patients (16%) who had video-EEG studies (with and without EEG seizures), and were commonly observed in younger patients (Fig. 3B). PFA was found in 27% of all video-EEG records in children from birth to age 1 year compared with 8% in those 14 years or older (Fig. 3B; $P=0.0065$). EEG-identified seizures were found in 299 patients (44%) and did not show a difference by age (55% birth to age 1 year, 52% over age 14 years; $P=0.45$). Of those with video-EEG identified seizures, 84 had PFA. PFA identified patients with epilepsy with a sensitivity of 28% (84/299), a specificity of 94% (360/382), and accuracy of 65% (444/681; Chi-square; $P<0.0001$). PFA was commonly observed in younger patients with seizures (45% from birth to 1 year compared with 12% 14 years or older; $P=0.0011$; Fig. 3C).

When present, PFA Identified Children with Seizures

Of the 106 patients with PFA, 84 (79%) were found to have EEG-ictal events on video-EEG. Of the 22 patients who had PFA but no captured seizures, 19 were known to have epilepsy based on clinical history and in 3 cases, referred from outside physicians, the history of epilepsy was unclear. Thus 103/106 (97%) children with PFA had epilepsy by behavioral and EEG criteria. It is also important to note that in this cohort none of the patients with exclusively non-epileptic events (i.e. did not have both epileptic and non-epileptic events) had interictal sleep PFA on their video-EEG.

Interictal PFA Identified Regions of Ictal EEG Onset

Of the 84 patients with interictal PFA and ictal events, 28 have focal PFA, 10 demonstrated multifocal PFA, 5 had bilateral PFA, and 41 had generalized PFA. Their ictal events were focal in 29 patients, multifocal in 8, bilateral in 2, and generalized in 45 patients. Excluding the patients with generalized PFA ($n=41$), PFA localized exactly to the scalp EEG site of ictal onsets in 15%, PFA sites covered a larger area than EEG ictal onsets in 30%, and PFA areas were smaller than ictal onset sites in 55% of cases. Again excluding those with generalized PFA, the location of the PFA was frontal in 59% of patients, temporal in 57%, central in 57%, parietal in 33%, and occipital in 24% of cases. The presence of PFA did not statistically differ among the five anatomic locations ($p = 0.29$) or between the two hemispheres ($p = 0.18$). For all 84 patients with PFA and ictal onsets, the anatomic location of the site of PFA agreed with the site of EEG-ictal onset with a sensitivity of 91% (494/544), specificity of 65% (193/296), and accuracy of 82% (687/840; Chi-square, $P<0.0001$). Even in the subset of patients without generalized PFA, sensitivity was 88% (109/124), specificity was 65% (193/296) and accuracy was 72% (302/420; $P=0.0003$). Of

the 84 patients with interictal PFA and ictal events, EEG ictal onsets began with β - and γ -range frequencies similar to the interictal PFA events in 67 (80%) patients.

PFA-Evolution

Thirty-five children had 2 or more video-EEG where one of the records was performed in 2001 to 2003 and the other occurred in 2000 to 2004 (i.e. expanding the time period to include one year before and one year after). The reason for the second video-EEG included a second look at pre-surgical consideration (n=12), unclear nature of postoperative behavioral events (n=3), new seizure events with different semiology (n=12), and exacerbation of seizure pattern including possible status epilepticus (n=8). The mean ($\pm$ SD) interval between the two video-EEG's was 1.0 ± 1.0 years.

In this cohort, all cases showed PFA in at least 1 video-EEG except 1 case (n=34). There were no differences between the sub-group of patients with PFA and multiple EEG studies with the rest of the PFA cohort for gender ($p = 0.49$), age of seizure onset ($p = 0.71$), or age at first video-EEG ($p = 0.31$). Of the 34 children that showed PFA on at least 1 video-EEG, 25 (74%) showed progression with the second EEG study, 5 (15%) showed improvement, and 4 (12%) records remained the same.

Of the 25 children with PFA progression, 6 showed seizures from a new location, 8 had seizures over a wider scalp region, and 11 had the same seizure pattern with a wider area of PFA (Table 1). Of the 25 with PFA progression, 19 (76%) patients showed worsening of their seizure frequency or severity. Of the 4 children whose PFA remained the same, progression was not possible in 3 cases as they began with generalized PFA at the initial video-EEG and continued with generalized PFA in the second record (ceiling effect). The PFA of the remaining child, who had probable cortical dysplasia by neuroimaging, continued to be focal over the same electrode. Of the 5 children who showed PFA improvement, 2 had complete PFA resolution after surgery (i.e. PFA-containing region was removed) and have been seizure-free postoperatively (Fig. 1). Two more improved from generalized to focal PFA, and 1 showed resolution of focal PFA. The 3 children with PFA improvement had concomitant seizure improvement, two by medication changes and one by institution of the ketogenic diet.

Clinical Characteristics of Patients with PFA

In the 2003 calendar year, 69 children with intractable epilepsy were evaluated for surgical candidacy at UCLA, and 19 (28%) had PFA. Of these 13 (19%) had infantile spasms on video-EEG, and 11 (85%) showed PFA, which was a higher frequency than similar aged children without infantile spasms (Chi-square, $P < 0.0001$). PFA was not associated with other seizure types, such as simple partial seizures, complex partial seizures, absence seizures, partial or generalized tonic, tonic-clonic, atonic, and myoclonic seizures ($p = 0.29$).

By etiology/substrate, 35 of 69 (51%) had unknown etiologies to their seizures; six of those (17%) had PFA. Eleven of 69 (16%) had acquired etiologies (localized stroke, n=4; trauma, n=1; diffuse hypoxia/ischemia, n=1; cavernous angioma, n=1; Rasmussen syndrome, n=1, history of viral encephalitis, n=1; tumor, n=1; hippocampal sclerosis, n=1); two of those 11 (18%) had PFA. Nineteen of 69 (28%) had developmental etiologies (cortical dysplasia,

n=12; heterotopia, n=3; tuberous sclerosis complex, n=2, hemimegalencephaly, n=1; holoprosencephaly, n=1); nine of those 19 (47%) had PFA. Finally, 4 of 69 (6%) had genetic etiologies (chromosomal translocation, n=2; chromosomal duplication, n=1; Kabuki syndrome, n=1); two of those 4 (50%) had PFA. The frequency of PFA by etiology was not statistically different (Chi-square, $P>0.10$).

The mean age ($\pm$ SD) of those with PFA (3.1 ± 3.6 years) were younger than children without PFA (10.5 ± 4.9 years, $P<0.0001$), similar to the larger cohort. The mean ($\pm$ SD) frequency of seizures was higher in children with PFA (25.5 ± 52.6 seizures/day) compared with those without PFA (4.8 ± 16.8 seizures/day, $p=0.04$). For this latter analysis, clusters of spasms were considered as single seizure events. The presence of PFA on video-EEG was not associated with differences in gender, age of seizure onset, duration of epilepsy, AED type at the time of video-EEG, number of AEDs, or histopathologic diagnosis.

Discussion

In a mostly pediatric cohort, this study found that pathologic interictal paroxysmal fast (β and γ frequency) activity (PFA) recorded during non-REM sleep was useful in the evaluation of patients with and without seizures. In patients mostly under age 18 years, PFA was found in 16% of all video-EEG records, and in 28% of individuals with seizures. In those with EEG-identified seizures, PFA was observed in 45% of children 1 year or less compared with 10 to 12% of those older than 14 years. When present, PFA identified individuals with seizures by behavioral and EEG-criteria with 97% sensitivity, and were not observed in patients with exclusive non-epileptic events. PFA localized to the site of scalp EEG-ictal onsets with 91% sensitivity and 82% accuracy, and ictal onsets began with β and γ EEG frequencies, similar to the interictal PFAs, in 80% of patients. Serial video-EEG studies found progression of PFA in 74% of patients that corresponded to increased seizure frequency or severity in 76% of cases, and the presence of PFA was associated with increased seizure frequency. PFA was more frequently observed in patients with infantile spasms (85%), but did not show a preference in patients with acquired (18%), developmental (47%) and genetic (50%) etiologies. Thus, PFA, when present, was most often observed in younger children, identified patients with epilepsy, and localized to scalp regions of EEG-ictal onsets. We propose that interictal scalp PFA is a surrogate marker in identifying regions of epileptogenesis and epileptic networks that can be recorded in a proportion of very young patients non-invasively during non-REM sleep.

Our results compare and contrast with findings from previous studies that evaluated fast EEG-transients in patients with and without seizures, and show a number of similar features as high-frequency EEG oscillations recorded with intracranial electrodes. For example, prior studies, in mostly adult patients where sleep recordings were not uniformly performed, reported scalp PFA in 0.2% to 3.4% of patients with a slightly higher percentage in pediatric patients (Gibbs et al. 1943; Nealis and Duffy 1978; Rodin et al. 1976). Our results found a much higher percentage of patients with PFA, especially in children under age 3 years with seizures, and these pathologic oscillations were not found in individuals with non-epileptic events. Similarly, while we found that young children with infantile spasms often displayed PFA, there was no association of PFA with acquired or developmental etiologies as had been

previously suggested in smaller cohorts (Green and Wilson 1961; Nealis and Duffy 1978). Such findings support the concept that if patients demonstrate PFA on interictal non-REM EEG studies, they should probably be evaluated with prolonged video-EEG studies to determine if they have epilepsy. Furthermore, our findings agree with other authors' conclusions that PFA are not always a sign of epileptic encephalopathy (Halasz et al. 2004). Thus, scalp-identified PFA appears to be independent of the pathologic processes that produce seizures although they are more frequent in young children. Why younger children demonstrate PFA more readily than older patients is unclear, but it may involve the thinner skull and scalp in infants allowing for better transmission of faster EEG signals or differences in the type of epilepsies in the pediatric population (Tao et al. 2005). Of additional interest, scalp PFA and high-frequency intracranial EEG oscillations were more frequently observed during non-REM sleep, suggesting an undetermined interplay between cortical-cortical and cortical-sub-cortical networks in their production (Nita et al. 2007; Staba et al. 2002; Staba et al. 2004; Timofeev and Steriade 2004; Urrestarazu et al. 2006; Wendling et al. 2005).

Our study also found that interictal PFA localized to the region of scalp ictal EEG onset zones with high sensitivity and accuracy, ictal onsets in these patients often began with β - and γ - frequencies. These findings are again similar to previous studies showing that high-frequency EEG oscillations localize to ictal onset sites, and that resections of these zones are associated with excellent seizure control post-surgery (Fisher et al. 1992; Jirsch et al. 2006; Worrell et al. 2004; Worrell et al. 2002). Hence, our data and the literature suggest that scalp-identified PFA and intracranially-identified fast-frequency EEG signals appear to be electrophysiological elements of the epileptogenic process (Bragin et al. 2002a; Jirsch et al. 2006; Rampp and Stefan 2006). This raises the question of whether interictal scalp recorded PFA are markers of the same pathologic process leading to high-frequency EEG oscillations. In our study, unfortunately, the high-frequency filter settings prevented recording of EEG frequencies above 70 Hz. Thus, future studies will need to determine the frequencies of PFA in young children and attempt to determine if the source of PFA on the scalp are the same as faster intracranial EEG oscillations.

The reader should be aware of the inherent limitations of this study when considering the results. For example, this was a retrospective survey where the presence of the PFA was based on review of the video-EEG reports. The advantages of this approach was that a large cohort, spanning several years, could be reviewed with focused re-review of only those video-EEG records reporting PFA. However, the reader should be aware that we may have underreported the number of children with PFA in this study. Also, our study design allowed us to identify that PFA was more frequently observed in younger patients, especially under age 1 year and those with infantile spasms. However, the reason why younger cases more readily demonstrate PFA compared with older patients cannot be discerned from our study design. Thus future studies should prospectively assess patients for the presence and location of scalp PFA and study a larger group of younger patients, perhaps with neuroimaging to measure skull thickness, to discern why PFA was more common in younger children. Despite these limitations, our study provides preliminary evidence that interictal scalp PFA localize to EEG-ictal onset zones making them useful markers of epileptogenesis in children with seizures, and that PFA has other characteristics similar to very-fast EEG oscillations

recorded with intracranial electrodes. This raises the possibility that interictal PFA recorded using other techniques, like magnetoencephalography with magnetic source imaging (MEG/MSI), might better identify fast EEG-transients like PFA, and provide non-invasive methods to identify patients with epilepsy and determine ictal sources and epileptic networks within the brain (Akhtari et al. 2006; Wu et al. 2006).

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Figure 1.

Focal interictal PFA. A) An example of focal interictal PFA over the right central region during sleep in a 9 year old boy. Ictal onsets associated with left facial twitching corresponded to right central seizure onset on video-EEG, and right posterior frontal/central focal cortical dysplasia on MRI. Notice PFA from the C4 electrode high-lighted in the second red box. B) Closer inspection of Fp2-F4 and F4-C4 channels containing sleep spindles of 11.5 Hz alpha frequency, both by visual inspection and computer analysis. C) Closer view of F4-C4 and C4-P4 channels containing faster beta frequencies, both by visual inspection and computer analysis. Time scale of 30 mm/sec, with high-pass filter of 1 Hz and low-pass filter of 70 Hz, sampling rate of 200 Hz. D) Spectral analysis of frequencies 14 Hz and higher for F4-C4 channel (first graph), F3-C3 (second graph), and the difference between these two channels (third graph) for this patient's non-REM sleep period. Notice peaks at 15 and 17 Hz corresponding to PFA episodes.

Figure 2.

Bilateral interictal PFA. A) Example of bilateral frontal PFA during sleep in an 11 year old boy with atypical absence and generalized tonic-clonic seizures of bi-frontal onset on video-EEG, normal cerebral MRI, and a significant family history of epilepsy. B) Closer inspection of channels F8-F4, F4-Fz, Fz-F3, and F3-F7, containing beta frequency of 27.5 Hz, both by visual inspection and by computer analysis. Time scale of 30 mm/sec, with high-pass filter of 5 Hz and low-pass filter of 70 Hz, sampling rate of 200 Hz.

Figure 3.

Bar graphs showing: A: The number of video-EEG studies by age from 2001 to 2003 for this study. B: The percent of all video-EEG studies by age that showed PFA. C: The percent of video-EEG studies with PFA from patients that also had seizures on the same video-EEG by age.

Table 1

Cases showing PFA progression

PFA Progression Category	Number of Patients	Number of Patients Showing Worsening Seizure Progression
No PFA to		
Focal PFA	5	5
Multifocal PFA	2	2
Bilateral PFA	1	1
Generalized PFA	7	4
Focal PFA to		
Expanded Focal PFA	2	1
Multifocal PFA	1	1
Generalized PFA	1	1
Multifocal PFA to		
Generalized PFA	1	1
Bilateral PFA to		
Generalized PFA	1	1
Progression Involves More than 1 Pattern	4	2
Total	25	19