Sleep modulation of epileptic activity in mesial and neocortical temporal lobe epilepsy: A study with depth and subdural electrodes

Rodrigo Rocamora a,⁎, Ralph G. Andrzejak b,1, Jordi Jiménez-Conde c,2, Christian E. Elger d,3

a Epilepsy Monitoring Unit, Department of Neurology, Hospital del Mar, Passeig Marítim 25-29, 08003 Barcelona, Spain
b Department of Information and Communication Technologies, Universitat Pompeu Fabra, Carrer Roc Boronat 138, 08018 Barcelona, Spain
c Department of Neurology, Hospital del Mar, Passeig Marítim 25-29, 08003 Barcelona, Spain
d Department of Epileptology, University of Bonn, Sigmund Freud Str. 25, D-53105 Bonn, Germany

A R T I C L E   I N F O

Article history:
Received 14 January 2013
Revised 11 April 2013
Accepted 12 April 2013
Available online xxxx

Keywords:
Epilepsy
Sleep
Modulation
Invasive
Electrodes
Temporal
REM sleep

A B S T R A C T

This study characterizes the spatial–temporal distribution of epileptic activity in mesial and neocortical temporal lobe epilepsy (TLE) assessed by subdural and depth electrodes during sleep. We determined in 13 patients the frequency, lateralization, and localization of interictal epileptic discharges (IEDs). As compared to the waking state, IEDs increased in light sleep (196%, p < 0.05) and in deep sleep (601%, p < 0.05) but did not change significantly in REM sleep (∼8.33%, p = 0.94). From 11 patients with unilateral TLE, in all cases, IEDs lateralized to the seizure onset side during REM sleep and the waking state. In mesial TLE, IEDs tended to shift in an anterior–posterior axis and remained always localized in the amygdalo–hippocampal complex. By contrast, in neocortical TLE, the maximal activity moved in a mesial–lateral axis between neocortical and mesial structures. Twenty-six seizures were registered in 7 patients, 22 of which occurred in light sleep and 4 in wakefulness, but none occurred in deep or REM sleep.

© 2013 Elsevier Inc. All rights reserved.

1. Introduction

The manifestation of ictal and interictal epileptic activity in TLE changes considerably across the sleep–wake cycle. It is an intriguing problem considering that very few studies have been performed on this topic. Sleep modulates epileptic activity through changing brain-synchronizing mechanisms. Nonrapid eye movement (NREM) sleep and rapid eye movement (REM) sleep have unique neurophysiological correlates and involve distinct neuroanatomical circuits [1]. Furthermore, the neural organization in NREM sleep can be differentiated in light and slow-wave sleep, which in the same form represents two different systems of neural network organization [2]. The main limitation of the available knowledge on sleep modulation of epilepsy is that the majority of studies have been performed with scalp electrodes and pooled different forms of focal epilepsies involving different epileptogenic networks.

There are discrepancies in the assessment of interictal activity from surface vs. invasive EEG recordings across the sleep–wake cycle [3,4]. The reason is that, with scalp electrodes, a cortical area of 10–20 cm is necessary to generate a recognizable interictal spike or ictal rhythm and, therefore, most subtle activity is not registered [5]. Particularly in TLE, the exact impact of the sleep–wake cycle on epileptic behavior remains controversial. Furthermore, to our knowledge, it has not been described whether mesial TLE behaves differently from neocortical TLE during sleep. This information can be relevant in the context of presurgical diagnosis in which a correct interpretation of aspects such as localization, propagation, lateralization, and shift of the epileptic activity is essential for an appropriate therapeutic approach.

The aim of this study was to characterize, by means of extensive bilateral invasive recordings targeting mesial and neocortical structures of the temporal lobe, all changes in lateralization, activation–inhibition, and spatial–temporal distribution of interictal and ictal activity during sleep. The use of such an invasive approach is unique for the detailed and exhaustive characterization of epileptic phenomena reducing almost completely biases such as propagation, filtration, attenuation, or distortion. In particular, we studied a homogeneous patient group with neocortical and temporo-mesial forms of TLE.
2. Methods

We studied 13 patients with medically refractory TLE who underwent invasive diagnostics in the course of their presurgical evaluation in the Department of Epileptology at the University of Bonn (Table 1).

These patients were a homogeneous group in the sense that all had only focal seizures of temporal lobe origin. In all patients, neurological examination was within normal limits. No major psychopathology was found. The decision of an additional invasive evaluation was taken because: (a) the lateralization of the seizure onset zone (SOZ) was unclear, (b) the information obtained from MRI (or functional neuroimaging) was incongruent with the scalp-derived SOZ, or (c) psychometric data disclosed major memory deficits of both verbal and visuospatial memory functions suggesting possible involvement of both temporal lobes. The protocol included an inpatient magnetic resonance imaging (MRI) with a special protocol for epilepsy. A comprehensive neuropsychological evaluation was performed in all patients. During invasive monitoring, antiepileptic drugs (AEDs) were partially or totally discontinued in all cases. The polysomnography (PSG) was carried out at the end of the presurgical evaluation when patients were again at therapeutic serum levels.

2.1. Polysomnography (PSG)

An all-night PSG was performed in an isolated monitoring room simultaneously with the invasive EEG recording. Patients were seizure-free for at least 24 h before the PSG. Sleep stages were scored from 30-s epochs according to the recommended criteria of the American Academy of Sleep Medicine (AASM). We considered total sleep time (TST) and percentage of wakefulness, light sleep (N1 and N2 were grouped together for this purpose), slow-wave sleep (N3), and REM sleep. The montage of scalp electrodes for sleep classification included the following: C4 (or C3), CZ, T4 (or T3), O2 (or O1), and Cb1 (or Cb2), electrooculogram (EOG), electromyogram (EMG), and electrocardiogram (ECG). All signals were recorded in a 128-channel system amplifier. Sleep staging was performed using bipolar montages. The low-pass frequency filter was set at 85 Hz, and the high-pass frequency filter was set at 0.53 Hz. The data were stored, after a 12-bit A/D conversion, in a data acquisition system with a sampling time of 5.76 ms.

2.2. Intracranial EEG (iEEG)

Both temporal lobes were symmetrically implanted with subdural electrode strips (SES) for chronic eCoG recording with two basal temporal and one lateral electrode on each side. SES, containing a total of 28 subdural electrode contacts, were implanted according to a standardized protocol (Fig. 1).

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>Seizures</th>
<th>Age at onset</th>
<th>Duration (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>m</td>
<td>38</td>
<td>CPS, GTCS</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>f</td>
<td>21</td>
<td>CPS, CPS, GTCS</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>m</td>
<td>18</td>
<td>CPS, CPS, GTCS</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>m</td>
<td>34</td>
<td>CPS, CPS, GTCS</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>5</td>
<td>m</td>
<td>46</td>
<td>CPS, CPS, GTCS</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>f</td>
<td>19</td>
<td>CPS, CPS</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>f</td>
<td>36</td>
<td>CPS, CPS</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>f</td>
<td>28</td>
<td>CPS, CPS, GTCS</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>f</td>
<td>42</td>
<td>CPS, CPS</td>
<td>1</td>
<td>41</td>
</tr>
<tr>
<td>10</td>
<td>m</td>
<td>25</td>
<td>CPS</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>f</td>
<td>38</td>
<td>CPS, CPS, GTCS</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>12</td>
<td>f</td>
<td>33</td>
<td>CPS, CPS</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>m</td>
<td>33</td>
<td>CPS, CPS, GTCS</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Average</td>
<td>31.6</td>
<td>Average</td>
<td>11.9</td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>6.7</td>
<td>Standard deviation</td>
<td>11.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The intracranial electrode arrays were composed of platinum/iridium contacts 4 mm in diameter with 2.3 mm of exposure separated by 10-mm center-to-center spacing. In addition, two 2.4-mm long depth silastic electrodes with 10 contacts each, 3 mm of intercontact distance, 5 mm of center-to-center spacing, and 1 mm of contact radius were implanted bilaterally through an occipital burr hole. With this implantation schema, 48 electrodes were available for invasive recordings of the temporal lobes in each patient. The electrode placement was performed with stereotactic control along the longitudinal axis of the hippocampus. The anterior contact was placed at the amygdaloid nucleus. The exact localization of SES and depth electrodes was determined after implantation by CT and MRI scans. Sequential bipolar montages with a sensitivity of 300–700 μV/cm, a time constant of 0.3 s, and an 85-Hz high-frequency filter were used.

2.3. Interictal epileptic discharge (IED) analysis

Determination of IEDs was performed after sleep staging. We performed a visual score of definite spikes and sharp waves in all 48 intracranial electrodes and in the simultaneously used scalp electrodes. The criteria were adopted from Gloor and included: (a) isolated, triangular paroxysmal waves with an amplitude of at least twice that of the preceding 5 s of background activity, lasting <80 ms (spikes) or 80–120 ms (sharp waves), regardless of whether or not they were followed by a slow afterpotential (slow wave), and (b) the presence of an electrical field in the adjacent electrodes [6]. One of the authors (R.R., German board of EEG and PSG) performed visual detection of IEDs. For all patients, the IED frequency (IEDs/min) was calculated. The IED data were combined with sleep stages by using a software program specially developed for this purpose by one of the authors (R.G.A.). The lateralization of IEDs was adapted from the criteria used by Adacchi et al. and defined as follows: IEDs were considered lateralized if more than 75% of them occurred on one side [7]. This lateralization percentage for each sleep stage was calculated by taking the maximum IED frequency in one temporal lobe, dividing it by the sum of both maximal frequencies, and multiplying the result by 100.

2.4. Seizure analysis

All patients had focal seizures in the course of the presurgical evaluation, but for the purpose of this study, only the ictal activity registered during the all-night PSG was considered. Ictal activity was evaluated for lateralization, onset, progression, and distribution. Seizure onset (SO) was defined as the first sustained alteration in background EEG activity. Mesial TLE was diagnosed when the SO was localized in the depth electrodes with the contacts corresponding to the amygdalo–hippocampal complex. Neocortical TLE was considered if the SO was limited to the basal or lateral subdural electrodes. Sometimes, this was apparent as a sudden electric flattening, followed by rhythmic low-amplitude fast activity (LAVA). In some patients, this flattening was not registered. In other patients, a transient rhythmic alpha or delta activity became visible after iEEG flattening and before multiple spike discharges.

2.5. Statistical analysis

We compared IED rates (IEDs/min) in light sleep, slow-wave sleep, and REM sleep against the rates registered in wakefulness across patients. For this purpose, we used a Wilcoxon paired signed-rank test since the distributions across patients could not be assumed to be normal and also to account for the sample size.

The expected number of seizures for each sleep stage was set to the proportion of time spent in each stage. A chi-square goodness-of-fit test was used to assess whether the observed number of seizures differed significantly from the expected number in the different sleep stages.
and wakefulness. For all statistical tests, the level of significance was set at $\alpha = 0.05$.

3. Results

3.1. Sleep stages

The mean total sleep time (TST) was 323 min, and the mean time in bed (TIB) was 359 min (SD: 62 min). The mean time of sleep stages, as a percentage of TIB, was as follows: W, 10.2%; N1–N2, 61.0%; N3, 20.5%; and REM 8.3%. All patients were asleep for at least 5 h during the observation period and presented all stages of NREM and REM sleep.

3.2. Interictal activity

The EEG of all patients exhibited IEDs in all sleep stages (Table 2). Median spike frequencies (spikes/min) were 1.2 (SD: 5.81) in W, 3.56 (SD: 3.96) in N1–N2, 8.42 (SD: 5.4) in N3, and 1.1 (SD: 3.96) in REM. Eleven patients showed maximal spike frequency during N3, one patient in W, and one in N1–N2. We compared the median spike frequency of each stage with the spike frequency observed in W. There was an increase of 196% ($p = 0.023$) in N1–N2, an increase of 601% ($p = 0.002$) in N3, and a nonsignificant reduction of $-8.33\%$ ($p = 0.94$) in REM (Fig. 2).

A 100% lateralization was observed in only one patient. In the other 12 patients, bilateral discharges with different grades of lateralization were registered. Using the defined cut-off lateralization value of 75%, 12 of the 13 patients (92%) lateralized both in REM and W. Only 9 of 13 cases (69%) showed lateralization in N1–N2. During N3, 11 patients lateralized (84%). When the data were pooled across all sleep stages, only 10 patients lateralized (>75%).

For correspondence analysis with SOZ, only the 11 patients with unilateral TLE were considered. Of these patients, the spike lateralization observed during REM and W (10 cases) corresponded always to the SOZ. Lateralization in N1–N2 was found in only 8 of 11 patients, but this was concordant with the SOZ in all cases. In N3, 10 patients showed lateralized IEDs which were concordant with the SOZ in 9 patients and contralateral to the SOZ in one patient. When pooled across all sleep stages, 9 patients had lateralized IEDs, which in all cases corresponded to the SOZ (Table 3).

Table 2
Frequency of IED represented as spikes/min in all patients. Sp/min: spikes/min (mean), SD: standard deviation.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Wakefulness</th>
<th>N1–N2</th>
<th>N3</th>
<th>REM sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.32</td>
<td>2.69</td>
<td>8.85</td>
<td>2.83</td>
</tr>
<tr>
<td>2</td>
<td>1.88</td>
<td>6.18</td>
<td>12.39</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>1.20</td>
<td>1.73</td>
<td>5.04</td>
<td>2.42</td>
</tr>
<tr>
<td>4</td>
<td>1.70</td>
<td>3.56</td>
<td>11.58</td>
<td>2.00</td>
</tr>
<tr>
<td>5</td>
<td>0.50</td>
<td>1.66</td>
<td>4.93</td>
<td>0.24</td>
</tr>
<tr>
<td>6</td>
<td>1.03</td>
<td>1.86</td>
<td>5.24</td>
<td>0.89</td>
</tr>
<tr>
<td>7</td>
<td>6.36</td>
<td>13.30</td>
<td>20.98</td>
<td>14.66</td>
</tr>
<tr>
<td>8</td>
<td>0.18</td>
<td>1.32</td>
<td>3.71</td>
<td>0.33</td>
</tr>
<tr>
<td>9</td>
<td>21.10</td>
<td>11.07</td>
<td>18.58</td>
<td>2.23</td>
</tr>
<tr>
<td>10</td>
<td>1.06</td>
<td>3.57</td>
<td>5.36</td>
<td>0.76</td>
</tr>
<tr>
<td>11</td>
<td>8.50</td>
<td>9.26</td>
<td>12.39</td>
<td>6.35</td>
</tr>
<tr>
<td>12</td>
<td>0.74</td>
<td>3.12</td>
<td>7.50</td>
<td>0.73</td>
</tr>
<tr>
<td>13</td>
<td>0.77</td>
<td>7.29</td>
<td>8.42</td>
<td>1.10</td>
</tr>
<tr>
<td>Sp/min</td>
<td>1.20</td>
<td>3.56</td>
<td>8.42</td>
<td>1.10</td>
</tr>
<tr>
<td>SD</td>
<td>5.82</td>
<td>3.96</td>
<td>5.40</td>
<td>3.96</td>
</tr>
</tbody>
</table>
We also analyzed the spatial distribution of IEDs on the depth and subdural electrodes in the different sleep stages and related these findings with the localization of the SOZ (Fig. 3).

This analysis revealed shifts in the localization of the maximal interictal activity during different sleep stages and wakefulness. This change was observed either in the longitudinal axis of the amygdalo–hippocampal complex (anterior–posterior shift) or in a transversal axis (mesial–lateral shift). In the case of mesial TLE, the observed shift was always anterior–posterior (9 of 9 patients), and we never observed a maximal focus of IEDs in neocortical structures. In contrast, in 3 of the 4 cases of neocortical TLE, we measured a lateral shift of the interictal activity. However, in spite of this difference, the overall maximal interictal activity in neocortical TLE was still localized in mesial structures.

3.3. Ictal activity

The localization of the SOZ, determined after the prolonged invasive monitoring, showed that 9 patients had mesial TLE, and 4 had lateral TLE. Six patients presented the SOZ on the left side, five patients presented it on the right side, and in two cases, it was bilateral. All 13 patients were on stable AED doses at the moment of the sleep analysis, and 26 seizures were observed during the one-night PSG monitoring in seven patients. Of these 26 seizures, four occurred in W, 22 in N1–N2, and none in N3 or REM (Table 4).

Comparing the observed number of seizures with the expected number, assuming a random distribution according to the proportion of time spent in each stage, differences were statistically significant (p = 0.014). In Fig. 4, the proportion of sleep stages, the number of seizures, and the expected number of seizures are shown.

Another characteristic was that all but one seizure were only subclinical. Also, these seizures were detected only by subdural and/or depth electrodes but not by scalp electrodes (used additionally during this study for sleep staging).

4. Discussion

In this study, we characterized specifically the epileptic activity in mesial and neocortical forms of temporal lobe epilepsy during sleep with invasive electrodes. This method permitted us to discriminate epileptic activity in areas with a higher sensitivity than with surface recordings and better signal-to-noise ratio allowing the recording of most of the generated activity in wide temporal lobe structures. Specifically in patients with TLE, a significant discrepancy has been reported when the IED’s distribution during sleep was measured with foramen oval (FoEs) or scalp electrodes [4].

In our work, we could confirm the strong activating effect of light and deep NREM sleep on the irritative area. In principle, IEDs during sleep are far more frequent than what is normally observed in scalp recordings. Indeed, IEDs are always present in all sleep stages, something which is seen infrequently in scalp EEG. Interestingly, slow-wave sleep (SWS) showed a statistically relevant change in IED frequency of 601% (p = 0.002), but no seizure occurred in this stage. This suggests that the synchronization in the delta band hinders the propagation of epileptic activity in the form of seizures. On the other hand, the inhibitory effect of REM sleep over the interictal activity was lower, and it showed
no statistical difference with wakefulness. In this regard, REM sleep behaved in a very similar form to wakefulness. Nonetheless, this lack of difference may be related to the low number of patients. With regard to brain cellular activity, wakefulness and REM sleep are closer than what is usually believed, and both are in contrast with NREM sleep, which is characterized by widely synchronized activities [2].

Our findings differ from other studies with semi-invasive methods. Clemens et al., using foramen oval electrodes, reported an increase of spiking frequency in TLE during light sleep. In contrast, the increase was observed in SWS when using scalp electrodes. To explain this discrepancy, a difference in archicortical and neocortical spike synchronization was suggested [4]. Former studies revealed no activation of IEDs during NREM sleep or reported activation during light NREM sleep, while others described more activation during REM sleep [3,8–15]. Most of these studies were performed in different forms of focal epilepsies, emphasizing the relevance of methodological aspects and the use of homogeneous groups of patients.

The correspondence with the SOZ was higher in wakefulness and REM sleep when the observed lateralization of IEDs is considered. Our results are in contradiction with previous reports on scalp EEG that suggest that IEDs occurring in non-REM sleep provide more accurate information for lateralization of the SOZ than those occurring during wakefulness [7]. However, other studies with scalp electrodes were consistent with our results with invasive evaluation [16]. This seems to be related to the inhibitory effect of waking and REM sleep on interictal activity making that the lateralization of IEDs during these stages have greater predictive value. Nonetheless, some remarks should be made. First, considering only wakefulness and REM sleep, both cases of bilateral TLE showed an IED lateralization > 75% (cases 5 and 7). Since these two patients had bilateral TLE, this can be regarded as a false positive IED lateralization. However, a consistent IED lateralization across all sleep stages was observed only in case 7. In another patient with unilateral TLE, the side of lateralization changed during sleep (case 9). In conclusion, a degree of IED lateralization greater than 75% during sleep is not enough to deduce the side of seizure onset with complete confidence. Nonetheless, it is highly reliable during wakefulness and REM sleep in the majority of cases. Therefore, the best time windows for spike lateralization during presurgical diagnosis seem to be wakefulness and REM sleep. It has to be remarked that our findings depict IEDs registered by invasive recordings, and, therefore, our conclusions should be restricted to the interpretation of similar recordings. Moreover, interictal activity lateralized contralateral to the SOZ in the EEG should not be a contraindication to advance in the presurgical diagnosis or to discard possible epilepsy surgery.

The comparison of spike activity between depth and subdural electrodes revealed a shift not only in spike frequency but also in spike localization in the temporal lobe across the different sleep stages and wakefulness. In mesial TLE, the major focus moved in an anterior–posterior axis from the amygdala to the hippocampus, and the maximal activity was always inside the amygdalo–hippocampal complex during sleep. However, in 3 out of 4 patients with neocortical TLE, the maximal interictal focus shifted in a perpendicular axis from mesial to lateral. In other words, in neocortical TLE, the maximal spiking during different sleep stages can occur in the neocortical lateral or basal structures. Nonetheless, even in these cases, the total maximal interictal activity in sleep was mesial. This behavior is important to recognize in order to perform an adequate interpretation of the maximal irritative area during sleep in the invasive presurgical evaluation of TLE.

Considering ictal activity, several studies in mixed groups of focal epilepsies have shown that seizures in partial epilepsies are more common in NREM sleep, indicating that they may arise especially in light NREM sleep [17,18]. In our studies, the observed ictal activity occurred only in light NREM sleep (N1–N2) emphasizing that in this stage, the level of synchronization is maximal, facilitating the manifestation of epileptic activity in the form of seizures. Interestingly, almost all the ictal activity recorded was subclinical and did not register in scalp electrodes, while all patients were on stable AED medication. This might suggest that in TLE, far more subclinical epileptic activity could exist during sleep than previously supposed which is not recorded on scalp EEG. This fact could have relevance in the interpretation of cognitive abnormalities observed in TLE and in the improvement that some patients show after temporal lobe epilepsy surgery. Also, the fact that most seizures were subclinical in our series was related to the short period of time considered for the analysis (6 h) and to the reintroduction of all AEDs. However, it is important to highlight that there is increased evidence in epilepsy diagnosis that subclinical seizures are of clinical relevance. Also, the distinction between clinical and subclinical is inherently ambiguous [19]. Even more, subclinical seizures commonly originate from the same cortical area as clinical seizures and are related to postsurgical outcome [20]. Nonetheless, as seizures were observed only in 7 patients, most of

![Image](image-url)
which were subclinical, our findings need to be further substantiated in larger studies.

Certainly, our study has some limitations. The modification of AEDs, although reintroduced at the moment of the recording, could alter the expression of ictal activity facilitating subclinical seizures. However, the influence of AED changes on IEDs is a matter of debate. Another limitation is that our patient group represents a special form of hard-to-diagnose TLE in which an invasive procedure is mandatory. Therefore, the number of evaluated patients is relatively small, resulting in a limited statistical power of the sample.

In summary, we present an exhaustive and detailed analysis of different aspects of epileptic activity during sleep based on invasive recordings in TLE. Our results allow us to propose a model of sleep neuromodulation of mesial and neocortical TLE. We provide further recordings in TLE. Our results allow us to propose a model of sleep neuromodulation of mesial and neocortical TLE. We provide further evidence for a trimodal form of sleep influence on TLE: N1–N2 sleep stages activate the seizure onset zone. N3 sleep activates the irritative zone, and REM sleep inhibits both zones. Moreover, in mesial TLE, the interictal activity shifts along the anterior–posterior axis of the hippocampal formation, while in neocortical TLE, it shifts from the mesial to the lateral cortex. Alternation in the side of maximal spiking focus during sleep or, even more, complete contralateral activation can be observed.

Further studies should conduct similar analysis in other forms of epilepsy to characterize the behavior of epileptic activity during sleep in specific neuronal networks.

Acknowledgment


References


