The Art of Encephalography to Understand and Discriminate Higher Cognitive Functions Visualizing Big Data on Brain Imaging using Brain Dynamics Movies

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Abstract
In recent decades a significant effort has been directed towards experimental and theoretical approaches aiming at the establishment of neural correlates of higher cognitive functions and awareness. These efforts produce massive amounts of data on imaging brain structure and functions, and efficient methods are in high demand to make these data easily accessible and understandable to human experts. Here we describe the development of qualitative tools and methodologies where large quantities of brain imaging data are processed and displayed for the purpose of visually discriminating the various stages of the cognitive processes. In this work we report and describe in detail a methodology inspired by the art of encephalography, whereby brain dynamics movies are created based on experimental data. The results are presented to identify large-scale synchronizations and de-synchronizations across broad frequency bands as a potential manifestation of the cycle of creation of knowledge and meaning. This visual process is also useful for the description of learning and adaptation processes in brains.

Keywords: Big Data, Brain Imaging, Electroctorigram, Visualization, Hilbert Transform, Synchronization, Criticality, Cognitive Cycle

1 Introduction

We invite the reader to have a look at the numerous fascinating successes that have been reported in the past decade concerning the neurophysiology of higher cognition and consciousness, producing massive amounts of brain imaging data obtained by functional magnetic resonance imaging (fMRI),
magnetoencephalograms (MEG), electrocorticograms (ECoG), and electroencephalograms (EEG) (Freeman W. J., 1999), (Del Cul, Baillet, & Dehaene, 2007), (Seth, Dienes, & Cleeremans, 2008), (He & Raichle, 2009), (Koch & Tononi, 2011). In the present work we focus on measuring evoked potentials over the cortex through ECoG and over the scalp by EEG, when we consider the benefit of providing direct and prompt information on the electrochemical processes underlying brain operation (Freeman W. Q., 2012). Based on such measurements, the development of information-theoretical indices to characterize behavior (Stam, Nolte, & Daffertshofer, 2007), (Hild, Erdogmus, Torkkola, & Principe, Feature extraction using information-theoretic learning Pattern Analysis and Machine Intelligence , 2006) with special emphasis in detecting the onset of synchronization of neural activity across large cortical areas related to higher cognition (Quiroga, Kraskov, Kreuz, & Grassberger, 2002), (Freeman, Holmes, Burke, & Vanhatalo, 2003), has been very useful in providing an initial understanding of the dynamics which are produced by the brain when processing a stimuli in order to create knowledge and meaning.

One of the major challenges has been to devise means to discriminate between cognitive states and sensory stimuli based on brain imaging data. It is an important goal to develop quantitative methods for performing such classifications automatically, without the need of human experts. However, there is a need to provide a tool to support human experts such as physicians to perform the classification and diagnostics with the human eye by watching brain dynamics movies. This is just like a thorough training is required to become a wine taster in order to decipher the quality of certain produce by testing a sample. In the case of brain imaging, however, the training is visual instead of via the olfactory and gustatory systems, and the samples are brain movies instead of wine sips.

This approach we call the art of encephalography (Borges I, Filomena V, Faoro M, & Perez de Pernia, 1985) and through it we have identified an opportunity to fulfill the need for the development of a methodology where large quantities of data are displayed for the study and understanding of the neural correlates of higher cognitive functions and awareness. This work presents a new methodology based on the art of encephalography, in order to create brain dynamics movies to allow the visualization of different indices simultaneously, as well as the identification of synchronization and desynchronization transitions (Borges I, Filomena V, Faoro M, & Perez de Pernia, 1985), (Freeman, Ahlfors, & Menon, 2009), (Kozma, Puljic, & Freeman, 2012), while presumably the brain is creating knowledge and meaning. This methodology highlights the importance of visual inspection and training on ECoG and EEG signals.

The present work aims at expanding on and complementing previous studies based on rabbit electrocorticogram (ECoG) data (Thompson & Varela, 2001), (Barsalou, 2008), (Freeman W., 1975) towards a better understanding of cognition and consciousness. Brain dynamics MATLAB movies were created for each of the 39 runs of experimental ECoG rabbit data measured with an 8x8 array of electrodes on the visual cortex of one rabbit. In order to create these movies, different measurements were included: the analytic amplitudes squared (AA), the absolute instantaneous frequencies (IF) and signal amplitude minus average (SA). This has been done after band pass filtering and applying Hilbert transforms to the data for the different frequency bands of interest, namely: theta, alpha, beta and gamma.

The idea was to produce a set of different three-dimensional perspective displays (3D) as well as a set of plane perspective displays (2D), a vista from above, where large quantities of data are presented simultaneously for visual inspection and study. For this purpose we created three (3) different types of displays, which provide different information and complement each other. These displays allow a visual impression of the following: (1) significant brain events for each measurement (SA, AA, IF), (2) significant brain events across bands and (3) the different stages of the cycle of creation of knowledge and meaning (Davis & Kozma, 2012), (Davis & Kozma, 2013). The final product is a set of 32 movies that provide insight into different aspects of cognition and learning, and particularly about the hypothesized cycle of creation of knowledge and meaning (Davis, Kozma, & Freeman, 2013) in the window of 1 s post visual stimuli.
In this paper, we start with a brief characterization of the rabbit ECoG experiments, followed by an introduction of the Hilbert transform-based signal processing approach. We define the measurement indices used and explain in detail the process of production for the different movie displays. Some movie-frames of the different displays are presented to show the benefits of this methodology and how these brain dynamics movies can aid in discriminating the various stages of the cognitive process. The aim is to produce a wide bank of movies, of different data and different indices, which would be uploaded to a website with the purpose of sharing and opening the door for an interdisciplinary study about the creation of knowledge and meaning.

Next we describe the visual findings, which point to the clear synchronization and de-synchronization (Davis & Kozma, 2012) effects across frequencies during intensive cognitive activity, the detection and classification (Kozma & Freeman, 2002) of previously learned conditioned stimuli, and the clear recognition of the different stages of the cycle of knowledge and meaning with the differences found between CS+ stimuli and CS- stimuli.

Finally, we also point to some limitations of our methodology and how to overcome such limitations in the future. Our work has the potential to shed light on the constructive aspects of intention and creativity, in the context of universal values and behavioral responses, for the future benefit and peaceful development of humanity (Davis J. J., 2009).

2 Description of ECoG Experiments and data preprocessing

In order to test the proposed movie making methodology we used experimental data obtained from intracranial arrays of 8x8 electrodes implanted over the visual cortex of rabbits at the Freeman Neurophysiology Laboratory at UC, Berkeley (Barrie, Freeman, & Lenhart, 1996), (Freeman W. J., 2000). The animals learnt to discriminate a stimulus under the classical conditioning paradigm, where one stimulus was reinforced (CS+) and the other was neutral (CS-). Once the animals were trained, experiments were conducted to test the discriminative power and the learnt behavior of the rabbit when presented with CS+ and CS- stimuli. Each experiment had a duration of 6 seconds. The first half (3 s) was used as the background reference state. At time 3 s, a stimulus (light flash) was presented to the animal and the response was recorded for the last 3 s. The first and last 0.5 s were omitted since those periods were affected by the filtering procedure and particularly by the order of the Finite Impulse Response (FIR) filter applied.

We follow the preprocessing steps as described in previous studies (Kozma, Davis, & Freeman, 2012). The index measurements that we used for the creation of the MATLAB movies were: the signal amplitude (SA), the analytic amplitude (AA) and the instantaneous frequency (IF). Band-pass filters were applied in the theta, alpha, beta and gamma bands with parameters as shown in Table 1. The applied Hilbert transform methodology and the analytic signal construction followed the approach described in (Kozma, Davis, & Freeman, 2012).

Table 1: Parameters of the pass band filters over various frequency band

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Fstop (Hz)</th>
<th>FpassL (Hz)</th>
<th>FpassH (Hz)</th>
<th>FstopH (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theta</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Alpha</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Beta</td>
<td>12.5</td>
<td>16.5</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>Gamma</td>
<td>24</td>
<td>30</td>
<td>36</td>
<td>40</td>
</tr>
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</table>
This comprehensive analysis for all 64 channels taken as a spatio-temporal object, for each of the 39 experiments, over various frequency bands, produced a large amount of data that we used to create 624 (4 indices x 4 bands x 39 runs) different MATLAB movies. After that we combined and synchronized them with a movie-making program to create a final set of movies (3 types) to more efficiently study the brain dynamics associated with these experiments. For the purpose of this paper we produced a few samples of movie frame illustrations to show the potential benefits associated with this new methodology based on the art of encephalography.

In the next section we describe in detail, step by step, the methodology used for the creation of the different displays of brain dynamics movies.

3 Brain Dynamics Movies Production Methodology

Figure 1 shows the steps followed in the creation of the different displays of movies of different measures or indices for the rabbit ECoG signals.

![Figure 1: Movies Making Procedure Diagram](image)

Following is a description of the steps to produce the three (3) different types of brain dynamics movies.

**Step 1.** Prepare the MATLAB code in terms of band filter parameters, type of index and type of display (2D or 3D perspective). The four indices used are: signal amplitude minus average in 2D (SA2D), signal amplitude minus average in 3D (SA3D), absolute values of instantaneous frequency in 3D (abs (IF)) and Log10 of the analytic amplitude squared (Log10 AA2). The rabbit data is preprocessed as explained in the previous section using the Hilbert transform approach. Record the MATLAB movies
for 39 experiments and for the four different indices in the four different bands (624 movies in total). It is important to note that each movie for each experiment for one (1) index for a particular band is recorded in MATLAB time with a pause slow enough (0.1 s) to capture every frame or spatial pattern for each time step. Once recorded, each MATLAB movie contains 39 experiments for an index on a particular band and with a duration of 1 hour and 40 minutes (100 seconds). This makes a total of approximately 27 hours for the 4 indices and the 4 bands (100s x 4 x 4 = 1600s ~26 hours and 40 minutes).

Step 2. Download to the computer the 16 MATLAB movies, each containing the 39 experiments for a duration of approx. 15 min each movie for a total of approx. 240 min or 4 hours. (~15 min/movie x 16 movies ~ 240 min ~ 4 hours).

Step 3. Organize the editing project (1 per movie) in an editing software program according to the type of display to be produced (approx. 25 minutes per project). Figure 2 shows the 3 types of movie displays that can be produced, they are:

- **Type 1** exhibiting the 4 different bands (Theta, Alpha, Beta and Gamma) per index with a total of 8 movies;
- **Type 2** exhibiting the 4 different indices (SA2D, SA3D, Log_{10} AA^2, IF) per band with a total of 8 movies;
- **Type 3** exhibiting the 39 experiments per index per band with a total of 16 movies;

For **Type 1** and **Type 2** displays, the CS+ and CS-experiments are grouped separately and displayed in sequence, one experiment within each group (CS+, CS-) at a time. For **Type 3** the screen is arranged in such a way that all the CS-experiments are on the left and the CS+ experiments are on the right. Each of the 16 movies, eight (8) for **Type 1** and eight (8) for **Type 2**, have a duration of approx. 24 minutes comprised of 20 experiments with a duration of 1 minute 23 seconds each, played one after the other. Each of the 16 movies **Type 3** shows 39 experiments played simultaneously with a duration of 1 minute 23 seconds per movie.

It is important to note that for display **Type 1** (4 bands per Index) all 4 bands must be time synchronized for each experiment. This allows the viewer to capture brain events simultaneously across different bands. For display **Type 2** (4 Indices per Band), all 4 types of indices must be synchronized with each other for each experiment. This allows the viewer to capture brain events simultaneously from different complementary measures and perspectives of the system. In display **Type 3**, 39 experiments per band per index must be synchronized in order for the viewer to capture simultaneously what happens in all these experiments on one particular band from the perspective of one particular measure or index.

Step 4. Synchronize experiments included in the editing project. It is important to note that each experiment takes around 1.5 hours to synchronize. Each movie is comprised of 20 experiments, both for displays **Type 1** and **Type 2**, resulting in a total of 30 hours of intensive work needed to accomplish the synchronization task of one movie. As shown in figure 2, there are eight (8) **Type 1**, eight (8) **Type 2** and sixteen (16) **Type 3** movies. Therefore, for all 32 movies the total time associated with the synchronization task amounts to approx. 960 hours (~30 hours/movie x 32 movies). As it can be noticed, this step is the most strenuous and time consuming for the analyst.

Step 5. Corrections, and art editing. This step takes around 3 hours per movie, which makes a total of (~3 hours/movie x 32 movies) approx. 96 hours.

Step 6. Rendering an editing project. This step takes approx. nine (9) hours in a i7-4700MQ CPU for each project concerning **Type 1** and **Type 2** displays for a total of around (~9 hours/editing project x 16 editing projects) ~144 hours. The rendering time required for each **Type 3** editing project is around five (5) hours for a total of (~5 hours/editing project x 16 editing projects) ~80 hours. This gives a total
of (~144 +80) ~224 rendering hours.

Step 7. Exporting edited movie. This step takes approx. eight (8) hours for a high definition movie (1920:1080px) in a i7-4700MQ CPU for each Type 1 and Type 2 movies for a total of (~8 hours/movie x 16 movies) ~128 exporting hours. Exporting Type 3 movies takes approx. four (4) hours per movie for a total of (~4 hours/movie x 16 movies) ~ 64 hours. This comes to a total of (~128 +64) ~192 hours of exporting time.

Step 8. Finalizing corrections and speed calibration. If everything is in order, in other words there is no need for further corrections, the movie is imported into the project and is doubled in speed to produce the final movie. This process takes around 15 minutes per movie for a total of (15 min/movie x 32 movies) eight (8) hours.

Step 9. Final rendering. This task takes approx. 2 hours per movie for Types 1 and Type 2 and approx. 40 minutes per movie for Type 3, for a total of (~2 hours/movie x 16 movies + 0.6667 hours/movie x 16 movies) ~ 42 final rendering hours.

Step10. Exporting Final Movie. This task takes approx. 4 hours per movie for Types 1 and Type 2 and approx. 2 hours per movie for Type 3, for a total of (~4 hours/movie x 16 movies + 2 hours/movie x 16 movies) ~ 96 final exporting hours.

Once the movies are finished they are uploaded to a web page on YouTube for visualization (Freeman W. J., 2015), (Freeman W. J., 2015), (Davis J. J., 2015), detailed study and sharing with the larger community across continents. The final product associated to the analysis and processing of the data for one (1) rabbit is comprised of 32 different movies, something that takes approximately a whole year to complete by one full time analyst interacting with a part time team of researchers.

In order to reduce the production time a proper analysis will be required, also a rigorous study will

**Figure 2.** Movie types according to display arrangement: 4 bands per index, 4 indices per band and 39 experiments per index per band.
have to be conducted in order to establish the timing and duration of this steps with statistical significance. This will require analysis including more rabbits and perhaps different cortices, however these study and analysis is outside the scope of this paper.

In the next section we discuss some of the observations and results that may lead to further research in classification (Kozma & Freeman, Classification of EEG Patterns Using Nonlinear Neurodynamics and Chaos, 2002) and discrimination of cognitive functions.

4 Some observations and results

In this section we present movie-frame illustrations of the movies we have produced, with the aim of showing the benefits of displaying brain EEG and ECoG signals in the way we have suggested. The reader will appreciate that each type of display has different benefits associated with it, presenting different features. The reader will also be able to appreciate that the three (3) types of displays complement each other in providing a broader view of brain dynamics and particularly for this work, rabbit brain dynamics. This approach to the art of encephalography gives the researcher the possibility to learn and study deeply about what constitutes awareness, intuition and the construction of knowledge and meaning in a dynamical, geometrical, qualitative and fun way. This is like going to the movies to learn about the brain in order to understand the system dynamics and structure concerning the creation of knowledge, meaning and consciousness.

We will start with a set of movie-frame illustrations which identify the brain events associated with the different stages of the hypothesized cycle of creation of knowledge and meaning. Each movie-frame is associated with a step of the cycle of creation of knowledge and meaning. It is recommended that the reader study carefully previous works (Davis & Kozma, 2013), (Davis, Kozma, & Freeman, 2013), (Davis, Ilin, Kozma, & Myers, 2014) where the 5 steps of the cycle are explained in detail. Following, we briefly introduce the reader to these five (5) steps:

1. **Awe moment**: the initial distinct and strong impression that is due to direct exposure to novel and unexpected sensory stimuli.
2. **Chaotic Exploration**: the exploration of memory traces that describe the brain as a dynamical system searching through its reservoir of past experiences.
3. **Aha moment**: the recognition/identification of the searched clue meaningful for decision-making.
4. **Chaotic Integration**: a step whereby new knowledge is integrated as chaotic attractors in a dynamical system.
5. **Background Activity**: a return to the basal brain dynamics indicated by a dramatic drop in the indices.

In figure 3 we show a **Type 3** movie-frame illustration, displaying the 39 experiments of four of the five stages of the cycle for the SA over the gamma band. It is possible to observe the different behavior of the SA in the different stages of the cycle of creation of knowledge and meaning and the different behavior between CS+ and CS- experiments within each stage of the cycle. These sets of illustrations are a very good example of the advantages presented by this type of display.
For the **Aha moment** we can observe high synchronization and low signal amplitudes for the 39 runs for the Awe, Chaotic Exploration, Aha and Chaotic Integration moments.

**Figure 3.** Movie-frame illustrations of Type 3 Movies. The 8x8 Spatio-Temporal patterns for the SA over the Gamma band (30 Hz – 36 Hz), for the 39 runs for the Awe, Chaotic Exploration, Aha and Chaotic Integration moments.
runs, CS+ and CS-. In the Chaotic Exploration moment we observe a desynchronization period followed by a strong rise of the SA in large regions of the spatial array. Let’s remember that it is in the desynchronization period when we observe the “null spikes” (Davis, Kozma, & Freeman, 2013), (Freeman, Kozma, & Vitello, 2012) in some regions of the 8x8 spatial array, which is usually a different region than where the rise in amplitude takes place. Null spikes are best represented and captured by the Log10 AA² index. In this step we can already observe that there is a difference in the behavior of SA between the experiments associated to the CS+ and the CS- stimuli, something that has to be confirmed statically in future studies.

In the Aha moment illustration (same figure 3) we can also observe the tendency towards synchronization and the drop of amplitudes reflected in the SA. At this moment the CS+ and CS- experiments show some minor differences in behavior, which may lead us to conjecture that there are different delays or amplitude magnitudes associated with the different type of stimuli (CS+ and CS-). A thorough study of these differences, which can properly be observed in the movies, is out of the scope of this paper. Finally, in the chaotic integration moment we can observe the rise in amplitude and strong and abundant “null spikes”, showing a similar behavior to the step of Chaotic Exploration, however with the difference that the CS+ and CS- experiments can hardly be differentiated.

Figure 4 shows the Type 1 display for the IF in experiment #6, which is a CS+ based experiment. This display shows the synchronization-desynchronization transitions within the cycle of creation of

![Figure 4. Movie-frame illustrations of Type 1 movies. The 8x8 Spatio-Temporal patterns for the IF in the gamma, beta, alpha and theta band for experiment #6 CS+.](image)

the desynchronization period when we observe the “null spikes” (Davis, Kozma, & Freeman, 2013), (Freeman, Kozma, & Vitello, 2012) in some regions of the 8x8 spatial array, which is usually a different region than where the rise in amplitude takes place. Null spikes are best represented and captured by the Log10 AA² index. In this step we can already observe that there is a difference in the behavior of SA between the experiments associated to the CS+ and the CS- stimuli, something that has to be confirmed statically in future studies.

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knowledge and meaning, as well as the synchronization of de-synchronization moments across bands.

The above synchronization-desynchronization transitions as shown by the IF, derive from the analytic phase values which exhibit intermittent variations over time where some of the 64 signals (usually from contiguous channels) go apart from each other to return close at later moments, something described as phase cones (Davis, Ilin, Kozma, & Myers, 2014). These phase cones are intimately associated with the instantaneous frequencies (IF) in the form of large indeterminacies with values outside of the band pass filter. As shown in figure 4, we can observe where in the 8x8 spatial array and when in time these indeterminacies happen, something that could be useful for further analysis.

Figure 5 is a movie-frame illustration for Type 2 movies showing the four indices for the gamma band. In this movie we can observe the “null spikes” in Log10AA, which are somehow related to the frequency dispersions of the IF as observed in figure 5a. This is followed by an increase in analytic amplitude around a certain region of the array as shown in both the Log10AA and SA indices. It is important to observe that this increase in amplitude is associated with a high degree of synchronization across the 8x8 array reflected in very low dispersions of the IF, as shown in figure 5b. We can also see very clearly how the region where the “null spike” takes place in the 8x8 array (as observed in

Figure 5. Movie-frame illustrations of Type 2 Movies. The 8x8 Spatio-Temporal patterns for the 4 indexes in gamma band (Type 2) for a CS+ experiment #2 (a) time 3:39 (b) time 3:42.
Log$_{10}$AA, is the same as where the frequency dispersion increases dramatically (figure 5a). It is important to note that also in figure 5a, the subsequent raise in amplitude is associated with a different region of the array where interestingly the IF values fall within the ranges of the band pass filter, an indication of more synchronization.

With the **Type 2** movies it is very easy to view the tornado like patterns of behavior in the SA both 2D and 3D. These tornado like patterns are associated with the increase in amplitude at regions showing low frequency dispersions. Generally speaking, we have observed the sequential relationship of events between the null spike, the frequency indeterminacies (associated with phase cones), the rise in amplitudes and the tornado like patterns. With the **Type 3** movies it is possible to have a first impression of any distinctions between CS+ and CS- patterns that could be classifiable.

There are important features about the synchronization-desynchronization associated with the cycle of creation of knowledge and meaning and the sequential events that take place for different indices that can also be observed in the **Type 1** movies. This type of display shows how the tornado like patterns behave across bands, where for the gamma and beta bands, the tornados move faster than for alpha and theta while the tornado’s direction switches between clockwise and anticlockwise, simultaneously across bands. These types of observations and behaviors open up new possibilities for analysis and research to better understand brain dynamics.

### 5 Discussions and Conclusion

Based on the present work, we can make some important remarks. The methodology that has been presented here has successfully allowed us to display large quantities of data for the study and understanding of the neural correlates of higher cognitive functions. The Art of Encephalography has opened a door to the important role of visual inspection and training on ECoG and EEG signals, giving us a new perspective on the processes underlying cognition. This methodology also comes with the opportunity of building a data bank of brain dynamics movies, which can be of great support in learning and understanding the way the brain creates knowledge and meaning. It is an important step towards the way the cognitive neuroscience community introduces people from other disciplines and practices to a broader understanding of the brain to bridge the gap between physics and neurobiology, for example, in understanding brain field dynamics and consciousness and facilitate tools and biofeedback systems for people to learn interactively what is meaningful to them by means of movie displays.

This methodology and undertaking still has much room for improvement and new ideas, as well as for a broad spectrum of applications. It allows for the opportunity to create new types of displays and for the use of different kinds of indices like the Pragmatic information indices introduced in other studies (Davis & Kozma, 2012), (Kozma, Davis, & Freeman, 2012).

It is important to mention that the methodology can also be improved. We are looking for ways to increase the time efficiency for step four (4), which is the most time consuming step, and we think this could be done by: (1) improving the MATLAB code, (2) developing new movie editing techniques and (3) increasing the amount of analysts involved in that step of the process. The rendering and exporting steps which are computer time consuming could also be optimized by: (1) a faster CPU, (2) an extra computer for conducting these steps and (3) a reduction in the quality of the movie when appropriate.

We can also say that the present methodology provides new insights about the different events involved in cognitive processing during critical transition periods, when the classification tasks are
solved after the presentation of a certain type of stimuli. We can clearly observe: (1) significant brain events for each index, (2) significant brain events across bands and (3) the different stages of the cycle of creation of knowledge and meaning and the differences in post stimuli events for the CS+ and CS-stimuli.

As we have stated in other papers (Davis, Kozma, & Freeman, 2013), we strongly feel that the creation of meaning and knowledge arises in cortical activity instead of sensory input and is more likely to be found in spatio-temporal brain field dynamic patterns than in single neuron calculations. We are convinced that quantitative approaches hand in hand with Freeman’s cinematic ideas (Freeman W. J., 2015) will greatly complement the learning process about brain dynamics taking good advantage of the complementarity of qualitative and quantitative analysis about the nature of the structure of meaning. We would like to reiterate that this is a departure from the AI approach to a Nonlinear-linear Systems Dynamics approach that we see more fit for the work at hand.

Future applications of this methodology will encompass measuring EEG activity in humans while in different states to attempt an explanation and identification of different brain patterns while in relaxation, meditation, and physiological coherent states mediated by breathing, in contrast with stressful mental activity.

The direct benefit of producing movies in this unique way is that it allows for the simultaneous study and artful visualization of large quantities of data, improving dramatically both the understanding of brain dynamics and the efficiency of data analysis.

Various experimental approaches will be useful to find the answer to these challenging questions. We hope our findings based on ECoG analysis motivate further studies towards the identification of neural correlates of cognition and awareness experience through the integration of various experimental paradigms.

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