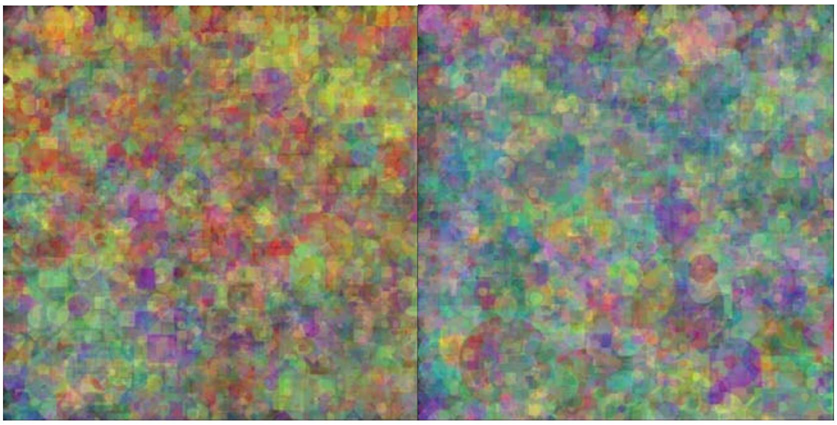
Daria Migotina

Paper: **BRAIN ART: ABSTRACT VISUALIZATION OF SLEEPING BRAIN**

Abstract:

This work introduces a novel artistic approach of looking at the electroencephalogram of the sleeping brain. Known imaging procedures generate two- or three-dimensional representations of the brain, highlighting different chemical, magnetic or electrical distributions, regions and structures. This paper is an attempt to visualize the data extracted from sleep EEG signals in a different way, by presenting them as global abstract images, which are visual representations of the macro- and microstructure of the sleep, generated by combination of different EEG features, events and states.

While global resulting images still contain some information regarding the structure and quality of the sleep, the main goal is to create a result that is aesthetically pleasant.



Left: Image, generated from the EEG signal of the normal sleeping brain

Right: Image, generated from the EEG signal of the baby sleeping brain

Topic: Art

Authors:

Daria Migotina
IST - Technical University of Lisbon, LaSEEB
Portugal

Carlos Isidoro
IST - Technical University of Lisbon, LaSEEB
Portugal

Agostinho Rosa
IST - Technical University of Lisbon, LaSEEB
Portugal

References:

[1] C.J. Aine, "A conceptual overview and critique of functional neuro-imaging techniques in humans: I. MRI/fMRI and PET", *Critical Reviews in Neurobiology* 9(2-3):229-309, 1995.

[2] Matt Pearson, "Generative Art", *Manning Publications*, 2011.

Contact:

dmigotina@laseeb.org

Keywords:

Generative Art, Data Visualization, Visual Abstraction, Computer Art, Biomedical Signal Processing, Electroencephalogram

Brain Art: Abstract Visualization of Sleeping Brain

Daria Migotina
LaSEEB, IST – Technical University of Lisbon, Portugal
e-mail: dmigotina@laseeb.org

Carlos Isidoro
LaSEEB, IST – Technical University of Lisbon, Portugal
e-mail: cisidoro@laseeb.org

Prof. Agostinho Rosa, PhD.
LaSEEB, IST – Technical University of Lisbon, Portugal
e-mail: acrosa@laseeb.org

Abstract

This work is an attempt to visualize the data extracted from sleep EEG signals in a different way, by representing them as global abstract images, which are visual representations of the macro- and microstructure of the sleep, generated by combination of different EEG features, events and states. All important information about quality of sleep and its structure is hidden behind the colors and shapes of the image; and every image is as unique as the whole night sleep of every subject.

The goal is to study if it is possible to encode whole night sleep EEG events into sequences of shapes and colours in order to obtain a painting which is aesthetically pleasant and allows a global appraisal of the dynamics and cyclicity of sleep and dreaming process.

1. Introduction

There are different techniques used for monitoring brain activity, such as positron emission tomography (PET), single photon emission computed tomography (SPECT), and magnetic resonance imaging (MRI), along with electro-encephalography (EEG). Advances in all these techniques are enabling scientists to produce remarkably detailed computer-screen images of brain structures and to observe neurochemical changes that occur in the brain as it processes information or responds to various stimuli.

Known imaging procedures, such as PET, SPECT and MRI, generate two- or three-dimensional representations of the brain, highlighting different chemical, magnetic or electrical distributions, regions and structures, and provide results in the form of colour or black and white images (Fig 1). Unlike these procedures, output of electroencephalography EEG is represented as a plain signal (Fig 1). Results provided by these techniques are mostly used for scientific purposes only and play no particular important role in the fine arts.

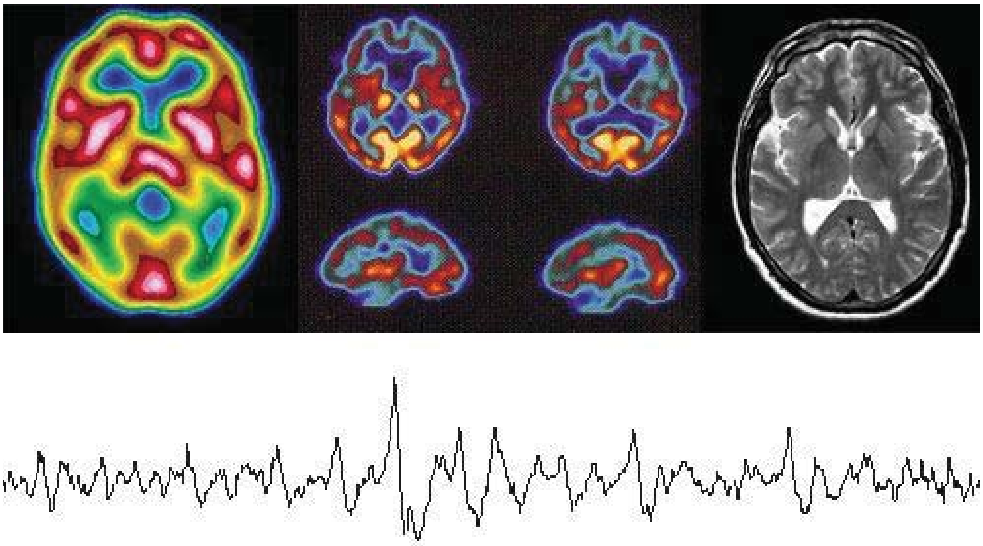


Fig.1 Top (left to right) > Examples of PET, SPECT, and MRI scans Down > Example of EEG signal

There have been, however, several attempts at using brain analysis results to generate artistic output, both by artists and scientists alike. Their work was mostly focused on integrating fragments of the brain signals and images into a final painting, as in [1] or on using real-time EEG analysis of an awakened brain in neurofeedback systems for painting without hands and creating visual images of individual's brain activity, as in [2,3].

This work introduces a novel artistic approach of looking at the EEG of sleeping brain. This study not only allows creating abstract images of the whole night sleep EEG signals, obtain from different subjects but also includes all important information about the quality and macro- and microstructure of their sleep. Sleeping brain images are represented by sets of different shapes and colors corresponding to the real EEG features, extracted from signals and transformed into unique images of single night.

Sleep is a dynamic process with known trend variation along the night, cycling between different states and dreaming episodes, as in [4]. The left-right side of the brains has common and independent activities making it a good candidate for left-right special differentiation. The frontal, central and posterior regions of the brain also differentiate from emotional, global and visual activities. The main problem of using these ideas is to find a way to code the EEG signals in a normalized way and then define a comprehensive mapping between features, colors and shapes in order to result in a pleasant and informative image.

First, we describe features extraction and encoding methods, used for obtaining the data from sleep EEG signals and their transformation into sleeping brain images. Then, two methods for images representation and final results will be discussed.

2. Features Extraction and Encoding Methodology

2.1 Band-Pass Filtering and Segmentation

The EEG waveforms are commonly classified according to their frequency, amplitude, and shape. The most known classification uses EEG waveform frequency – one of the main characteristics of the EEG signal. In accordance with manual analysis the classification of EEG frequencies on major bands (rhythms) was introduced, as in [5].

The following frequency rhythms are the most clinically relevant: Delta: < 4 Hz; Theta: 4 – 8 Hz; Alpha: 8 – 12 Hz; Sigma: 12 – 16 Hz; and Beta: 16 – 20 Hz. Our work deals with these five frequency rhythms in order to extract necessary information from the sleep EEG signal.

At first, five frequency bands 0.1 – 4 Hz (delta), 4.1 – 8 Hz (theta), 8.1 – 12 Hz (alpha), 12.1 – 16 Hz (sigma) and 16.1 – 20 Hz (beta) from the sleep EEG signals of channel C3-M2 by application of a 8th order Butterworth FIR band-pass filter were extracted. The absolute value of each filtered EEG signal was then plotted and, in order to provide a smoother shape for the signals, a linear interpolation method was applied.

Each filtered EEG signal was then segmented using specific segmentation procedure based on the threshold application. As a result, segments of five different types, corresponding to delta, theta, alpha, sigma and beta frequency characteristics, were obtained.

The next step was to combine segments from five filtered and processed signals in order to obtain events consisting of segments from different types. Frequency segments, appearing simultaneously throughout the EEG signal, were combined together by application of specified set of rules based on the information about durations of the segments and spaces between them. This procedure allowed excluding non-relevant data from the analysis and avoiding the use of excessive information. Thus, events carrying frequency information about analysed sleep EEG signals were created. In total, thirty-one possible combinations of segments were obtained. These combinations are referred to as types of events. For convenience, types of events were numbered from 1 to 31.

From each EEG signal, sequence of events of different types was obtained, and this sequence represents microstructure of a sleeping brain for particular night.

2.2 Sleep Stages: Macrostructure of Sleep

Macrostructure of human sleep has been described as a succession of five recurring stages: four non-REM stages and the REM stage. A sixth stage, waking, is often included. Waking, in this context, is actually the phase during which a subject falls asleep. Rapid eye movement (REM) sleep is marked by extensive physiological changes, such as accelerated respiration, increased brain activity, eye movement, and muscle relaxation.

Sleep quality changes with transition from one sleep stage into another. Stages are, in fact, discretely independent of one another, each marked by subtle changes in bodily function and each part of a predictable cycle whose intervals are observable.

In the middle of 1930s Loomis provided the earliest detailed description of various stages of sleep [6], and in the early 1950s Aserinsky and Kleitman identified rapid eye movement (REM) sleep [7]. Sleep generally is divided in two broad types: non-rapid eye movement sleep (NREM) and REM sleep. After a brief proliferation of several sleep classifications a standard emerged. Sleep Stages are scored according to “A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subject”, which was elaborated in 1968 by a committee co-chaired by A. Rechtschaffen and A. Kales [8].

NREM and REM occur in alternating cycles, each lasting approximately 90-100 minutes, with a total of 4-6 cycles. In general, in the healthy young adult NREM sleep accounts for 75-90% of sleep time (3-5% Stage 1, 50-60% Stage 2, and 10-20% Stages 3 and 4). REM sleep accounts for 10-25% of sleep time. Stages 2 and 3 repeat backwards before REM sleep is attained. So, a normal sleep cycle has this pattern: waking, stage 1, 2, 3, 4, 3, 2, REM. Usually, REM sleep occurs 90 minutes after sleep onset.

Since the purpose of this work is not only to create an aesthetically pleasant result, but also to provide informative images that would allow tracking of the quality of the sleep and its macrostructure, sleep stage information was also extracted from EEG for further image encoding.

2.3 Grouping of Events

It is well known that delta, theta and sigma frequencies are typical for sleep EEG, whereas alpha and beta frequencies more often observed in wakefulness EEG, although they are also present in the sleep.

Typically appearance of the rhythms in human EEG is following:

- Beta rhythm is associated with normal waking consciousness;
- Alpha rhythm predominantly originates from the occipital lobe during wakeful relaxation with closed eyes. Alpha waves are reduced with open eyes and drowsiness and sleep;
- Theta rhythm tends to appear during drowsy, meditative, or sleeping states, but not during the deepest stages of sleep;
- Sigma rhythm is normally observed during sleep;
- Delta rhythm occurs most frequently during stage 3 and 4 of NREM slow-wave sleep.

Based on this knowledge, events were grouped into twelve groups according to a specified set of rules. These groups are represented according to the information about the structure of the event (the combination and order of the segments inside the particular event) and its relation to the sleep-awake concept. For convenience, each group type was numbered from 1 to 12.

2.4 Encoding of EEG Events into Image Objects

Each EEG signal was analysed according to the segmentation and grouping methods, described above. At the end, EEG signals were transformed into sequences of events. Each event contains information about its type (1-31), corresponding group (1-12), duration in seconds and name of the sleep stage it occurs in.

After sequences of events are obtained, they can be used in creation of sleeping brain images. An image is created by converting information about each event in a sequence into a simple object; and inserting these objects into the same picture, taking their chronological order into account when determining their location.

Each object exhibits three different features: colour, shape and size.

1. The first feature takes into account information about the type of event and defines the colour of the object, choosing from a set of thirty one colours, corresponding to the particular type of current event. The following colours and their association with each event were chosen randomly (Fig. 2).

Fig. 2 Thirty-one colour, chosen for the encoding sleep EEG events into objects of the image. Each colour corresponds to a specific type of events.

2. The second feature has twelve possible values, corresponding to the group information of the current event, and is used to select shape of the object. There are six basic shapes (circle, square, rectangle, line, octagon, diamond), and each can be made opaque or transparent, depending on the corresponding group (Fig. 3).

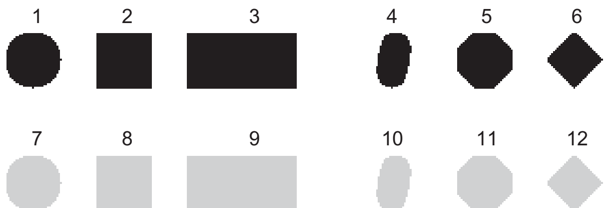


Fig. 3 Six basic shapes used in encoding sleep EEG events into objects of the image. Events from groups 1-6 are represented by opaque shapes, whereas events from 7-12 groups are represented by transparent shapes.

3. The third feature is based on the information about the duration of the current event and is used in determining the size of the object. Longer events result in larger objects.

3. Final Images Representation and Results

There are two different methods for representing sequences of events as images of the sleeping brain. Both of them include information about sleep stages, in which events occur during the whole night sleep.

Twelve whole night polysomnogram recordings (≈ 8 hours each) from normal healthy volunteers and from snorer patients are used in this study. The data were randomly selected from our database. From each polysomnogram recording, single EEG channel (C3-M2) is used in this study.

3.1 Representation Method 1

This representation method groups the events according to their sleep stage information. Five different images are generated, one for each stage, and then combined to generate the final result. For each stage, their individual events are analysed and placed on the respective image. To determine their location the average length for an event of that stage is calculated and then normalized so as to make each resulting stage image the same size. This value is then used as the mean size for the objects of that stage, and is also used as the distance between adjacent events. The events are placed on the image according to their chronological order, with the first event of a given stage being placed on the top left corner and then following a left to right, top to bottom order.

The final sleeping brain image is then created by taking all five stages' images (Stage 1, Stage 2, Stage 3, Stage 4 of NREM sleep and REM sleep), making them transparent and overlapping them over each other.

Resulting sleeping brain images for twelve subjects from healthy normal and snorer populations are represented in Fig. 4, 5.

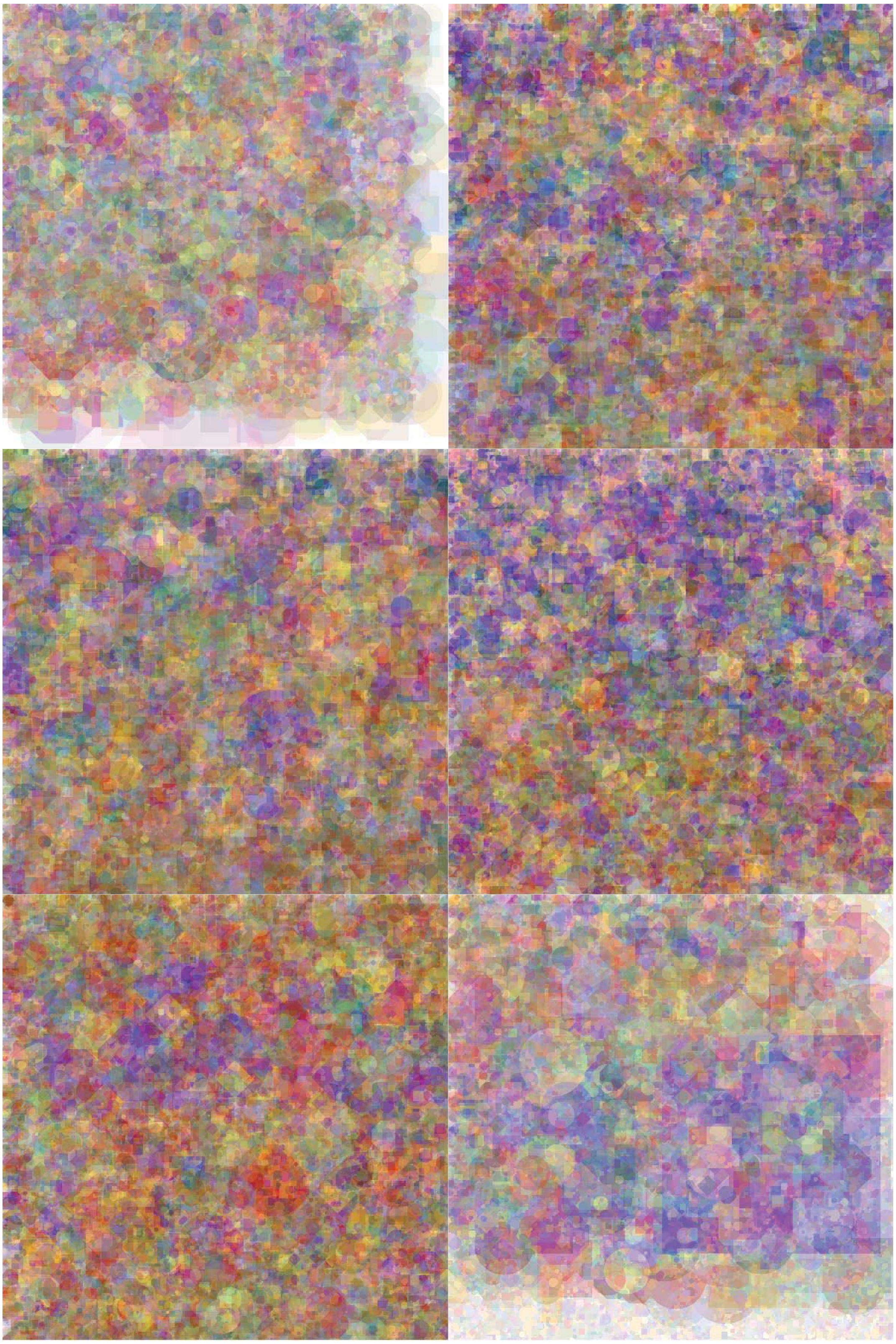


Fig. 4 Sleeping Brain Abstract Images for six snorer patients, created with representation method 1

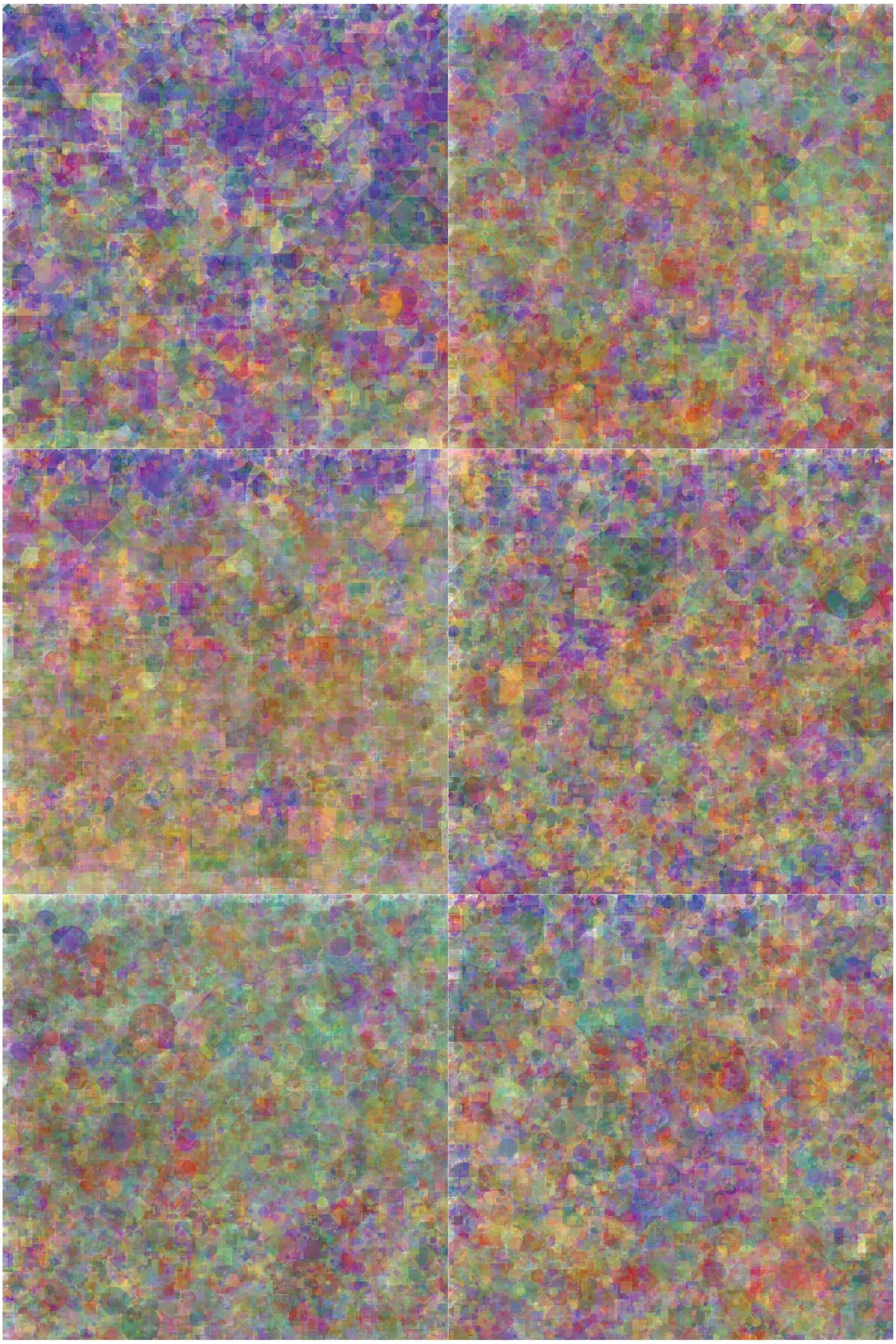


Fig. 5 Sleeping Brain Abstract Images for six healthy normal adults, created with representation method 1

3.2 Representation Method 2

This representation method changes the way the location for an object is determined, as well as the way of using stage information. The objects are now placed in a spiral pattern, starting on the centre of the image with the first event in the sequence and spiralling outwards in a clockwise direction, following events' chronological order.

Objects are spaced at specific distance from each other based on the calculated mean duration between all events (no distinct value for each stage was used as in first representation method).

In this method, stage information is used to determine the background colour for each object, providing information about durations of sleep stages and their cyclicity throughout the whole night.

The chosen background colour associated with each sleep stage is shown in Fig. 6.

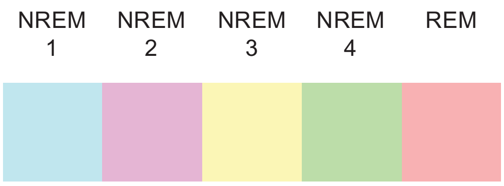


Fig. 6 Background colours corresponding to sleep stages

Resulting sleeping brain images for twelve subjects from healthy normal and snorer populations are represented in Fig. 7, 8.

4. Discussion

The main idea of this work was to represent sleep EEG signals in a different way, as abstract images of sleeping brain. The goal was to create images that are both aesthetically pleasant and informative. Two different representation methods were applied to the sequences of sleep EEG events for their transformation into images.

First representation method allowed creating very interesting and aesthetically pleasant abstract images of sleeping brain, but from the obtained results it is clear that informative side is missing. Although, one can say that images show some specific differences in whole night sleep among different subjects and populations, it is hard to provide a clear interpretation of those results. Since the distance between events is normalized so as to provide images of equal size for each stage, the information about event duration is distorted (stages with less events generate larger objects, even if the event's duration is shorter than events on more populated stages). Information about the sequence of sleep stages during the night is also lost. These issues make it difficult to analyse the resulting image from a sleep quality point of view.

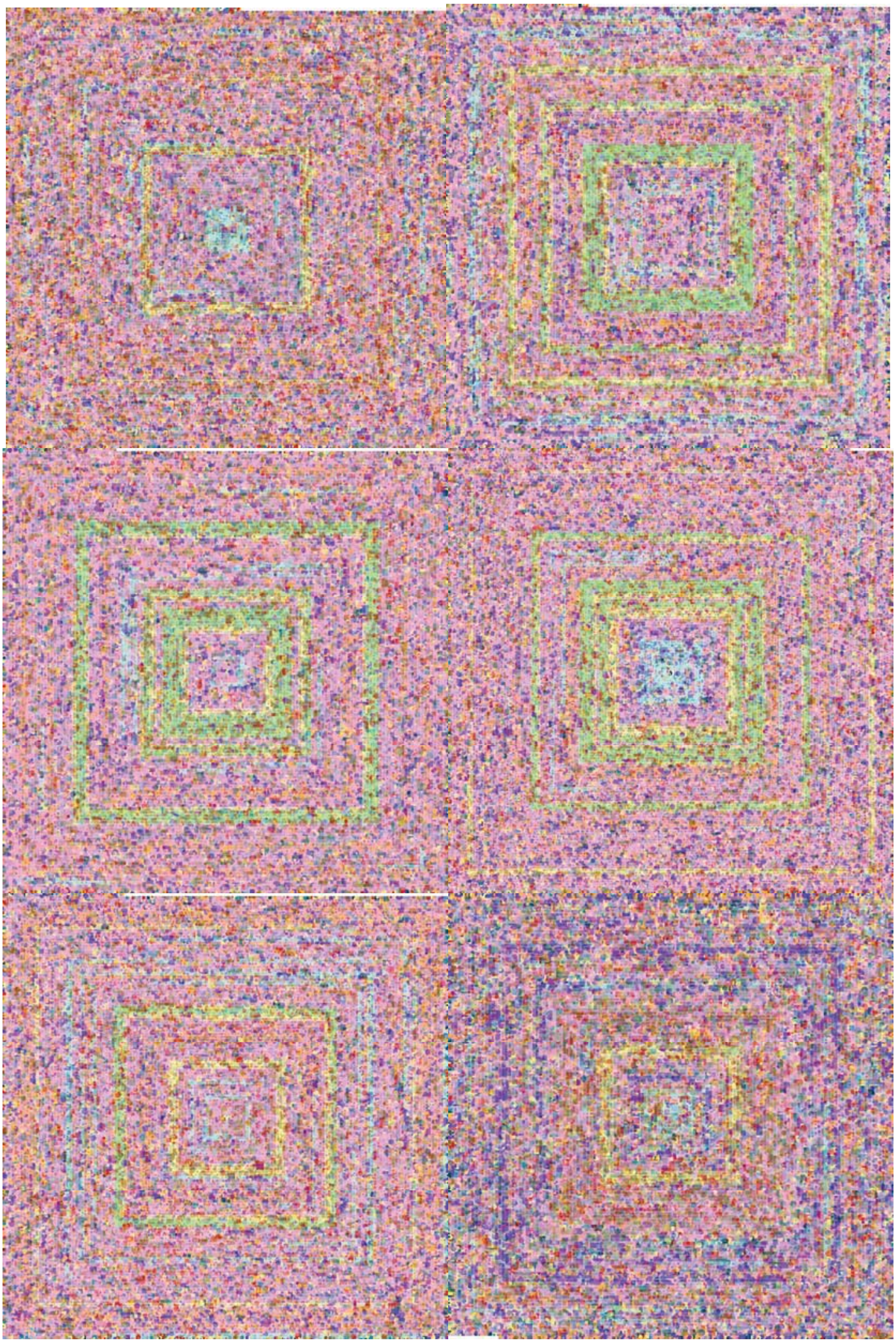


Fig. 7 Sleeping Brain Abstract Images for six snorer patients, created with representation method 2

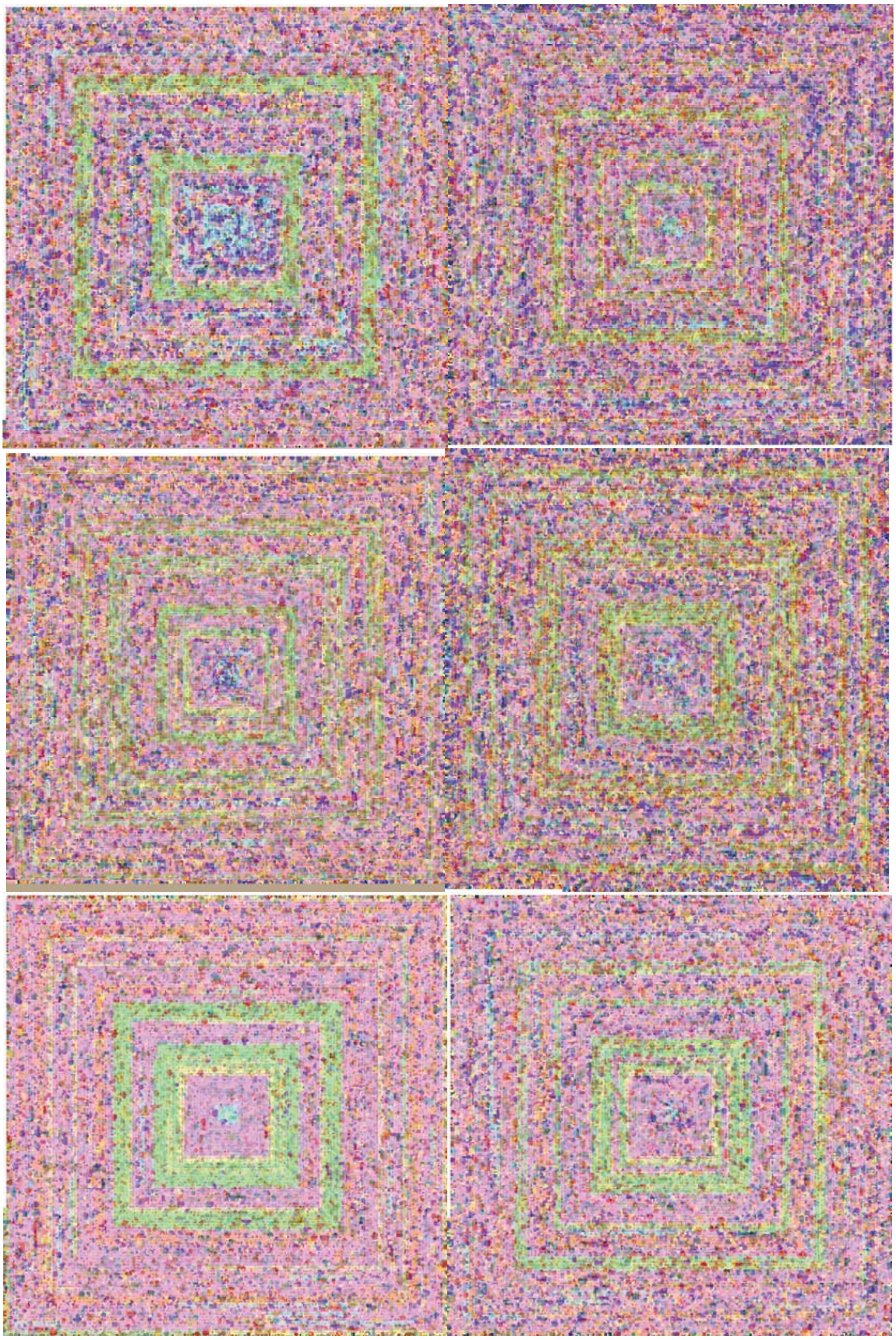


Fig. 8 Sleeping Brain Abstract Images for six healthy normal adults, created with representation method 2

Second representation method allowed creating abstract images of sleeping brain together with providing some information about quality of sleep of the subject and its cyclicity. Created images show how sleep stages replace one another and dynamics of events' changes during the night.

Whereas, first representation provides more interesting results, but makes it harder to interpret from a sleep analysis point of view, second representation method gives more detailed account of the subject's sleep, but might not be as interesting.

In the future work we will use more additional features and different effects for the objects (blurring, transparency), new shapes, and review the colours associated with events' types to have some resemblance between them.

6. Acknowledgments

This work was supported by project the FCT (ISR/IST plurianual funding) through the PIDDAC Program funds.

7. References

[1] Web: http://www.tulliofrancescodesantis.com

[2] Web: http://brainpaint.com/

[3] Kübler A., Halder S., Furdea A. & Hösle A., "Brain painting - BCI meets art", Proceedings of the 4th International Brain-Computer Interface Workshop and Training Course , pp.361-366, 2008.

[4] Swierzewski J., Stanley M.D., "Sleep Stages. Overview, Waking, Non-REM, REM, Sleep Cycle, Factors, Age", Sleep Channel, Healthcommunities.com, 2008.

[5] Gevins A., Rémond A., "Handbook of Electroencephalography and Slinical Neurophysiology, Vol. I: Methods of Analysis of Brain Electrical and Magnetic Signals", Elseiver, Amsterdam, 1987.

[6] Loomis A.L., Harvey E.N., and Hobart G.A., "Cerebral States During Sleep, as Studied by Human Brain Potentials", J. Exp. Psychol., vol. 21, pp. 127–144, 1937.

[7] Aserinsky E. and Kleitman N., "Regularly Occurring Periods of Eye Motility, and Concomitant Phenomena, During Sleep", Science, vol. 118, pp. 273–274, 1953.

[8] Rechtschaffen A., Kales A., "A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects", UCLA, Brain Research Institute/ Brain Information Service, Los Angeles, USA, 1968.