SONIC TRIPTYCHON OF THE HUMAN BRAIN

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ABSTRACT

This paper describes the motivation, data and sonification technique for three sound examples on the auditory display of human brain activity, selected and formatted as contribution to the ICAD aural submission category. The human brain generates complex temporal and spatial signal patterns whose dynamics correspond to normal (e.g. cognitive) processes and as well as abnormal conditions, i.e. disease. Our sonification technique *Event-based Sonification* allows to render multi-channel representations of the multivariate data so that temporal, spectral and spatial patterns can be discerned. Being a scientific approach, the sonifications are reproducible, systematic and the mapping is made transparent. Control parameters help to increase the saliency of specific features in the auditory display. This is demonstrated using data with sleep spindles, a photic response and epileptic discharges. Since all 'sonic pictures' are rendered with the same technique, a variety of dynamic phenomena related to different brain states are demonstrated as auditory Gestalts. Sonification of the EEG offers a meaningful complement of the prevailing visual displays.

1. INTRODUCTION

The human brain is the most complex organ/device in operation and a strongly investigated target in many disciplines, from medicine over cognitive neuroscience to psychology and computer science. Although the basic principles of neural activation are known, it is still unclear how the brain implements its fantastic processing capabilities at a larger scale, or how exactly malfunctions correspond to pattern changes. In particular, there is a need for novel techniques to elucidate how normal activity and disease-related abnormalities influence cerebral dynamics,

Sonification is a promising approach to better understand the brain since (a) cerebral activity forms complex spotio-temporal patterns of rhythms and synchronization dependencies. Listening is therefore ideal to pick up such structures and their changes over time; (b) brain activity is prominently organized in the spectral domain where rhythmic patterns at specific frequencies are known to correspond to brain activity – this naturally matches the built-in spectral decomposition of the listener's ears; and (c) brain activity is spatially organized over the cortex – which fits to our ability to interpret spatial sound patterns in terms of localised sources.

EEG audification (i.e. direct playback of the signal) is a standard technique in neurophysiology to observe the firing of individual neurons, yet for large-scale multivariate recordings audification is not the technique of choice. We present in this paper sonifications created by our approach of *Event-based Sonification* and show that this is a successful means to better understand the complex dynamics of the working and diseased brain.

2. EEG: RECORDING AND ANALYSIS

The electroencephalogram (EEG) is a standard non-invasive method to continuously record human cerebral activity at high temporal resolution. The EEG measures the electric potential on the scalp at pre-specified electrode positions with respect to a reference signal. The signals are typically depicted as multivariate time series as shown in Fig. 1. Neurologists try to detect characteristic patterns (e.g. related to epileptic conditions) from such visualizations, and are required to analyze hundreds of patient EEG recordings to develop this skill. Nevertheless, due to the overwhelming complexity of human brain dynamics important problems remain. We suggest that human auditory signal processing offers a complementary mode of perception of such data with specific benefits in a clinical setting [1].

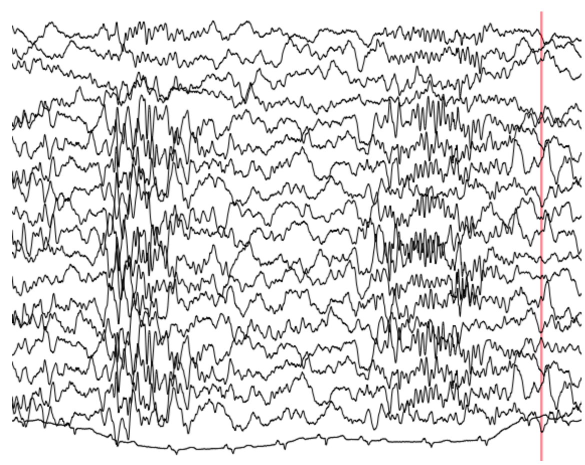


Figure 1: Typical signal plot of EEG data, here during sleep. Characteristic changes in the left and right half of the figure are caused by the so-called sleep spindles.

3. EVENT-BASED SONIFICATION

Many normal (e.g. sleep spindles, see Fig. 1) and abnormal (e.g. epileptic, Part 3, below) rhythms occur in the range of 0.1-30 Hz, corresponding to the phenomenon of rhythm rather than pitch in a real-time display. While it is easy to see global changes in rhythm as in Fig. 1 it is often hard to specify and interpret complex rhythmic relationships between multiple channels. A large number of sonification techniques have been proposed and tested, yet, from our current experience, Event-based Sonification seems to be the most promising candidate.

Event-based Sonification is a real-time method to transform the multivariate data stream (typically, between 19 and 30 channels, sampling rate between 100 and 1000 Hz) into a set of events which are then represented by sonic events whose superposition constitutes the sonification. As event we define local maxima in the data series, but we allow flipping of the signal polarity if necessary, for instance to better align the patterns of spike-wave discharges. For each event, the level difference to the previous minimum and the time difference to the previous maximum are extracted as important features for later use in the sonification.

Since even a single data series is a noisy mixture of several frequencies, there is the risk that by taking only local maxima relevant lower-frequency events are missed. This is coped with by defining a procedure to extract *hierarchic maxima*, which means to detect also the maxima of the maxima event series as maxima of 2nd order and so on until a lower bound (e.g. 1 Hz) is reached. From the time to the previous maximum at the order of analysis we can estimate the rhythm frequency, and accordingly we create sound events of different pitch so that faster rhythms are represented by rhythmical sound events at higher pitch. The detailed technique is more complex and explained in [1, 2].

There are two important parameters to filter the massive stream of sonic events according to a window of analysis: (i) we can set a center of interest on the frequency scale, causing nearby events to be pronounced in level and brilliance, (ii) we can set a threshold of rhythmical persistence, filtering of all events that occurred less regularly than defined by this limit, which eliminates sporadic or random events.

For example, for epileptic rhythms at 3 Hz (typical absence seizures), a corresponding center of interest frequency of 3 Hz and a high threshold leads to sonifications where spontaneous EEG is almost suppressed yet clearly rhythmic sound events stand out during epileptic episodes.

4. SONIC TRIPTYCHON - THE IDEA

For the current contribution we have selected three data segments recorded from different subjects/patients during different conditions. Each sonification lasts several minutes so that the listener can tune in to the typical soundscape of the signal. Despite the fact that the overall brain activation is largely unaffected by specific conditions (e.g. differences in extremely different emotional states will have essentially no impact on the EEG), many other conditions produce characteristic rhythmic changes. We have attempted to optimize the sonifications such that the most characteristic differences can be perceived from the audio stream. The three sonifications with more than 10 minutes duration give ample occasion to the listener to get accustomed to the stationary background patterns and slowly learn to differentiate normal from abnormal structure in the sound stream and thereby in the EEG data. The three 'sonic brain images' give three different perspectives[1] of cerebral activity. While the examples are rendered here for stereo presentation, they can be perceived as 16 channels spatial audio in our laboratory, creating the impression of an immersion in the brain. We emphasize that our sonification technique is strictly systematic and will render reproducible sonifications with the same data, so that the sound is a valid medium to interpret the underlying structure.

As a visual prelude to the sonification pieces, an animation is played that provides relevant background information for the experimental condition and patterns. Then the sound is played in a darkened room to reduce distraction from pure listening, as done previously in [3]. Media examples for the present contribution are provided at our website [2]

5. SONIC TRIPTYCHON PART 1: SLEEP EEG

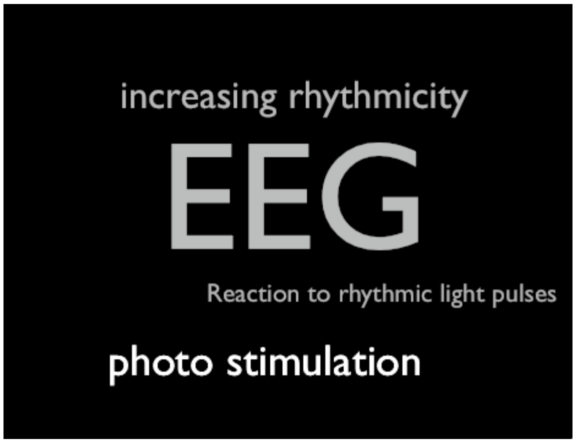
The first EEG data set is recorded during sleep. A characteristic pattern in stage 2 sleep is the so-called sleep spindle, episodes of activity in the lower beta band around 12-14 Hz. These occur in bursts interrupted by periods of reduced rhythmic activity. We use the center of interest frequency filter to improve contrast of activity in this region, leading to clearly audible event trains. Occurrence, duration, and rhythmic arrangement of sleep spindles can be perceived. In addition, the repetitive occurrence allows an estimation of mean duration and rhythmic variability. Since rhythm frequency maps to the pitch of the events, change of pitch is directly related to change of spindle frequency.

6. SONIC TRIPTYCHON PART 2: PHOTOSTIMULATION

The second EEG data set was recorded during photostimulation (PS), a technique to examine the influence of repetitive light flashes at certain frequencies on brain activity. Photosensitive subjects show a change of EEG background pattern in response to such stimuli and in epilepsy patients this can lead to a number of so-called photoparoxysmic responses, exceptionally even to the start of a seizure. The present data were recorded from a patient where the photoresponse was classified as type 4, i.e. abnormal activity was found during PS over most of the scalp. In the sonification we hear that during the stimulation a more and more pronounced rhythm at about 3 Hz is established which continues to the end of the recording. Note that the stimulus is not represented in the this sonification.

[1] or "peraudects", to use a newly invented sonic analogue term to spectare

[2] see our website http://www.techfak.uni-bielefeld.de/ags/ami/publications/HB2010-STO



7. SONIC TRIPTYCHON PART 3: EPILEPSY

The final EEG data set is from a patient with epilepsy. Following normal background activity for about one minute, the first seizure starts apparently spontaneously and spreads quickly over the entire cortex with a characteristic rhythm of about 3 Hz. During the seizure there is a stronger synchronization between channels (coincidences of events) and less rhythmic variability (events are not filtered due to higher regularity in repetition). Finally, epileptic activity dissolves and the dynamics returns to normal background EEG. There are two seizure episodes in the sound example. It is an interesting question whether there are any precursors of the seizures in the EEG data that could be detected in the sonification which but were overlooked in the plots. Devices optimised for this task could help to develop warning methods but such a goal was not pursued in the present context.

8. DISCUSSION AND CONCLUSION

From the EEG sonifications it can be understood that there is continued activity in the brain at a broad range of frequencies. Cognitive and emotional phenomena that are perceived as dramatic subjectively influence this permanent neural activity only to a very limited extend in single recordings. In the case of sleep EEG, the sleep spindles are very characteristic and quickly constitute an auditory gestalt that can be picked up, remembered and rediscovered, for example during the next phase of stage 2 sleep or even in sonifications of stage 2 sleep in another subject. Disorders that are associated with disturbances of sleep rhythms like depression could benefit from the auditory approach.

For the sonification of EEG during PS we have emphasized general rhythmic properties of the whole scalp. As the corresponding EEG responses are in general less regular one would define new features to make specific abnormal responses more salient for clinical applications. Of particular use is the possibility to work on-line, as e.g. the detection and risk management of photo-induced responses could be accelerated with the auditory mode of data display.

The epileptic EEG discharges are heard as rhythmic spatially distributed sound events with clear rhythmic relationships. In the auditory mode, the temporal evolution of the multivariate rhythmic patterns can be both intuitively understood and analytically studied, e.g. the slow frequency change during the seizure, the grouping of events in certain channels during some times but not in others and so on. The epilepsies have been named as one example of a dynamical disease [4] a class of disorders that is particularly characterized by qualitative changes in rhythmic patterns. We propose that all dynamical diseases are potential candidates for promising future developments in sonification research.

Concerning what to do next for the establishment of the technique in clinical practice we seem to face a ‘chicken or the egg’ dilemma: On the one hand, it is not yet clear what the best sonification technique will be for specific problems. On the other hand, who is willing to invest time to learn the ’sonic language’ without knowing that this is going to be the eventually most successful method? Our hope is that by starting with very concrete pathologies (e.g. epilepsy) we can optimize the sonification method such that already known patterns are displayed in both modes and will lead to the recognition and acceptance of auditory displays. This provides the opportunity for professionals to see the benefits to become familiar beyond this threshold of acceptance, and discover patterns which are beyond the current limit of understanding.

9. ACKNOWLEDGEMENT

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