Visualizing Deep Brain Stimulation Settings in Obsessive Compulsive Disorder Patients

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Abstract

Deep Brain Stimulation (DBS) is a new treatment being applied to Obsessive Compulsive Disorder (OCD) in which electrodes are surgically inserted into the brain. A large part of this treatment is calibration after surgery, where settings for the electrodes are adjusted to find the best long-term response. Complicating matters are the facts that the parameter space is very large, and that chronic responses may take days or more to surface. In this project, we address some of these problems through intuitive visualizations intended to shed light on important relationships between electrode settings and patient response.

1 Introduction

Obsessive Compulsive Disorder (OCD) is an anxiety disorder in which the individual is overcome by fears, anxieties, thoughts or impulses, usually of disturbing things. In response to these obsessions, the individual performs certain acts or rituals, often repetitively. For example, a person fearful of contamination might compulsively wash; a person afraid of starting a fire might have constant impulses to check the stove. OCD is common: it affects over 2% of the national population [3], and most people have experienced some OCD-like symptoms at some point in their lives.

Deep Brain Stimulation (DBS) is a new surgical procedure in which electrodes are placed directly into specific targets in the patient's brain. Electricity is supplied to the electrodes via thin wires that run through the skull and down the neck, connecting to a battery implant and control circuitry in the chest. By introducing an electrical signal in local areas of the brain, it is possible to interfere with brain activity and reduce symptoms. DBS was first used in 1987 and is already an established procedure for treating Parkinson's and related motor diseases. It is now starting to be applied to severe cases of OCD.

The effectiveness of the stimulation greatly depends on the placement, configuration and parameter settings of the electrodes. Without the right settings, DBS will not improve the patient's symptoms, and may even make them worse. In the current procedure for OCD, two leads are inserted into the brain, each with four electrodes. Each of the electrodes can be set to positive or negative potentials; many more parameters can also be varied, such as pulse width, frequency, amplitude, and current. This large parameter space presents a problem for doctors and technicians: What settings will produce the best chronic response in the patient?

2 Problems and Goals

The primary goal of this collaboration is to create and use visualization tools to find the configurations of electrodes that produce the best chronic responses. The end product will be a set of tools that can be used to research relationships in the data, and communicate those relationships with other researchers. The main questions we must address to find the best configurations are the following:

- *What is the relationship of electrode settings and acute patient response to the chronic response?* Some effects of stimulation might not be seen until days or weeks (or even years) after stimulation with a particular setting begins. Yet these are exactly the long-term responses we wish to improve. Is it possible to use the short-term response and the configuration settings to predict the chronic response? If so, this could help reduce calibration times by allowing acute responses to guide more of the process.
- *What are the effects of varying the anatomical placement of the electrodes?* Variations in placement are most likely a key factor in variation of responses across individuals. How does placement affect the settings needed to produce a given response in the patient? Is there some way to "compensate" for variation in placement using the configuration settings?
- *How reliable are the effects of changing settings?* For a given setting, how much does patient response vary within the same patient, or across different patients? I would expect the acute response may vary within one patient, but the chronic response should always converge to the same result in the long run.

We will address these questions by creating and using visualization tools for desktop computers. We will work mostly on the first problem, relating electrode settings, acute response, and chronic response. If we have time or find it necessary for comparing between patients, we may also address the effects of anatomical placement. In particular, we will focus on the following two specific questions:

- *Are there any acute "predictors?"* Are there any acute responses or side effects to stimulation that might signal a positive long-term response? If so, what are they? Potential candidates include ratings on mood, anxiety, depression, etc., and also side effects such as warmth or tightness in the face.
- *Which is the most important parameter?* Is it amplitude? frequency? pulse width? current? The answer to this question will not only allow doctors to choose better settings, but will

also provide evidence for exactly which areas, tissue types and neuron functions are targeted in an effective DBS configuration.

In addition, use of the tools we create will not be limited to the duration of the project. Researchers will be able to continue using them in the future to investigate and explore the data, as well as to communicate findings with other researchers.

3 Visualization Challenges and Techniques

The visualization component of this project is significant. The challenges facing us include:

- *High dimensionality.* The space of parameters and responses is very large. How do we present the user with all the relevant information in a way that enables them to gain insight into the relationships? How do we let the user find and then specify what the relevant data is? How do we allow the user to navigate through the space?
- *Sparse data.* While there is a fair amount of data, it covers the space only sparsely. This could present problems for some visual representations, especially those that require finer sampling (e.g. generating surfaces or interactively choosing settings with dials). On the other hand, it may benefit other techniques (e.g. glyphs, parallel coordinates).
- *Obscure relationship with chronic data.* We want to find the settings that lead to the best chronic response. But the eventual response is not known until weeks after a session, and by then other settings have been tried out. How can we accommodate this time delay? How can we create meaningful visual associations between long-term responses and data points from adjustment sessions?

Our first visualization tool, to be created in the first two weeks, will employ a simple yet powerful 2D interface (a mockup is shown in the Appendix). In it, the user places and edits components that offer different views of the data. These components use different visualization techniques, and can be interactive. In our first visualization, there will be a coarse-scale graph of patient response over time on the top of the screen. In this graph, the user can specify a time slice — a window in time that he/she is interested in. He/she can then specify and interact with visualizations of patient response and electrode settings, restricted to this time interval. Separate views are linked together by using consistent scales on the x-axis. Multiple patients or time slices can be specified, allowing the user to compare data between patients and times (see Figure 2 of the Appendix).

This visualization addresses the problem of relating acute data to chronic data: by specifying slices in time, the user can identify interesting times in the chronic response, and see what acute events happened in an interval before then. High-dimensionality is addressed by displaying each dimension in an appropriate format, and allowing the user to choose what to show and how to show it. We do not force an unnatural visualization, such as a 2D or 3D scatter-plot of the whole space.

After creating this first visualization, we will decide how to extend and improve the tool through close collaboration. A likely extension is to allow dimensions other than time to be sliced or displayed on the x-axis. This will allow us to explore relationships between arbitrary variables, which is necessary for determining which parameters are most important. It will also allow us to see which portions of the parameter space have been explored, and which still need to be investigated. Other possible extensions include using parallel coordinates, glyphs, Chernoff faces, animation, videos or pictures of patients' facial expressions, and data from PET, EEG and fMRI. A nice feature of the interface is that it can easily accommodate such extensions (see Figure 3 of the Appendix).

4 Previous Work and Significance

There are very few useful visualization tools for investigating DBS in OCD. Currently, doctors and researchers create plots in Microsoft Excel; there are no visualization tools beyond this. Our visualization tools will most likely be a great help to researchers on both current and future problems, allowing them to make insights that would not otherwise be possible.

In addition, we will find relationships between settings and patient response; in particular, we will aim to identify acute predictors. This will help reduce configuration times. Furthermore, we may also supply evidence for how DBS works by determining which parameters are the most important.

There is much work done on visualizing multivariate and multidimensional data [10, 5, 8]. Usually, however, existing visualization techniques only deal with discrete data points (e.g. dimension stacking, parallel coordinates, scatter-plots). They do not address the problem of relating acute data to long-term chronic response. Thus, while our visualizations will draw on existing methods, we will adapt and create new techniques that address this problem. In addition to this, the project may also result in new user interface techniques for multivariate/multidimensional visualization.

5 Work Plan

For this project, I plan to maintain very close collaboration. We will continuously improve visualization tools, with collaborative evaluations weekly or more often. The implement/evaluate/improve cycle will be repeated as many times as possible, hopefully leading to a useful tool and several answered questions in the psychiatry. In particular, I propose the following plan:

- **Week 1**. We will implement an interface to the database and the visualization framework described in section 3. We will also start to work on components for visualizing the data over time, and collaboratively evaluate the tools so far.
- **Week 2**. We will implement the slice intervals described in section 3, as well as components for line graphs, text, waveforms, and electrode on/off settings. This first tool will be used and evaluated extensively. Based on collaborative feedback, we will decide what to implement and improve in the coming weeks.

- **Weeks 3-4**. We will improve techniques for comparing between different times and patients. We will also investigate other visualization techniques and extensions as described in section 3.
- **Weeks 5-6**. Development and touch-up of final tools. This will involve a feature freeze, cleaning up and possibly doing more integration for what we have. We will create user documentation for the tools, and produce write-ups of the software, techniques used and new findings.
- Throughout the course of the project, we will use the tools to find acute predictors and to see which stimulation parameters matter the most.

6 Participants

Our team spans a wide range of experiences and backgrounds necessary for this project. Benjamin Greenberg is a leader in the fields of DBS and OCD. Erin Einbinder is also experienced in these areas, and knows the details of the patient data. Vadim Slavin has a solid physics background, which is necessary for understanding the electric stimulation and its effects. Nicholas Yang and David Eigen have graphics and user interface experience, as well as backgrounds in cognitive science and mathematics.

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Appendix

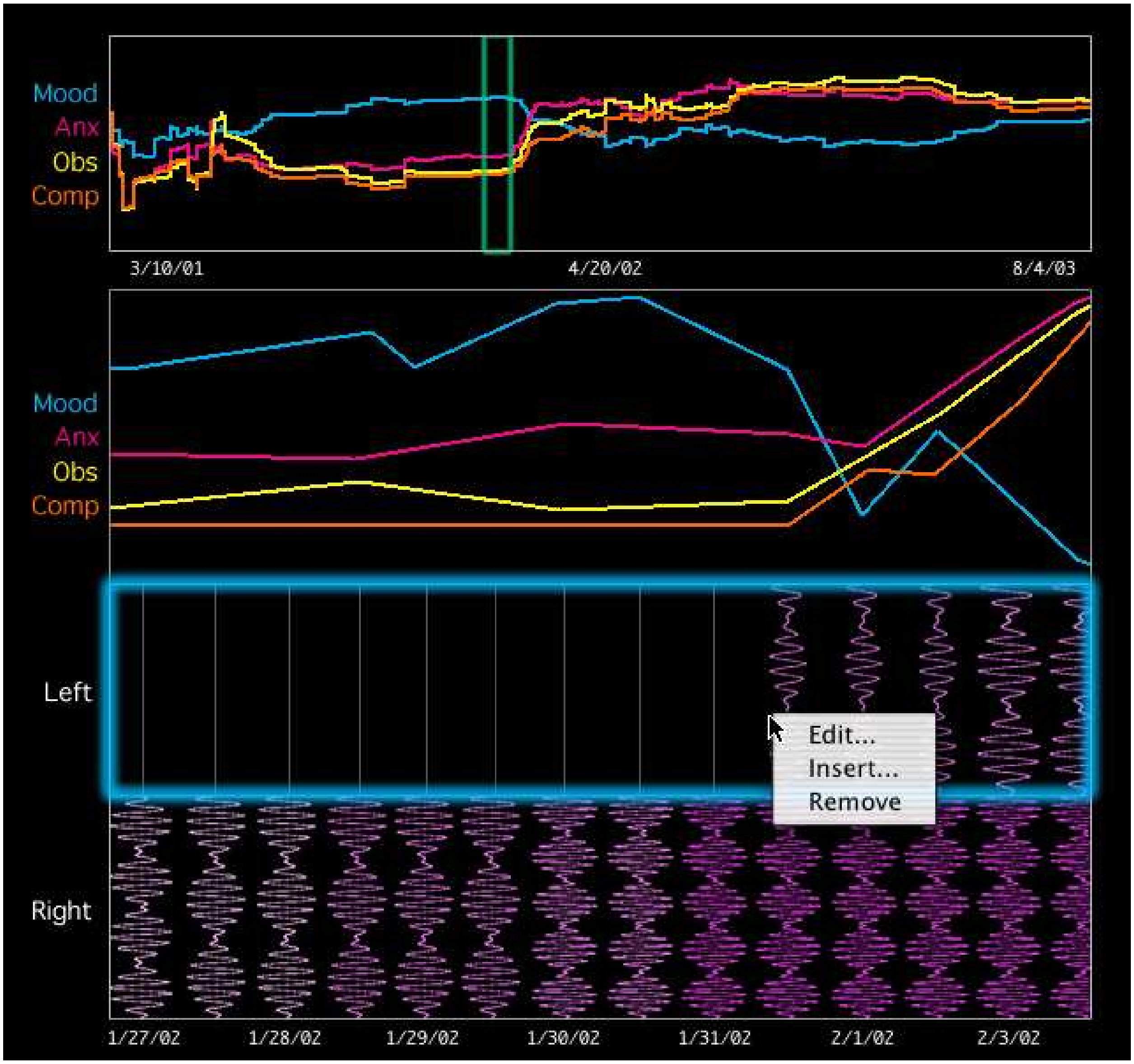

Figure 1: A potential visualization interface. The user can specify a time slice in the coarse-scale timeline above. Acute data for this slice is shown in the lower portion of the screen. The user can specify settings on how to display the data. Waveforms are used to convey electrode parameters.

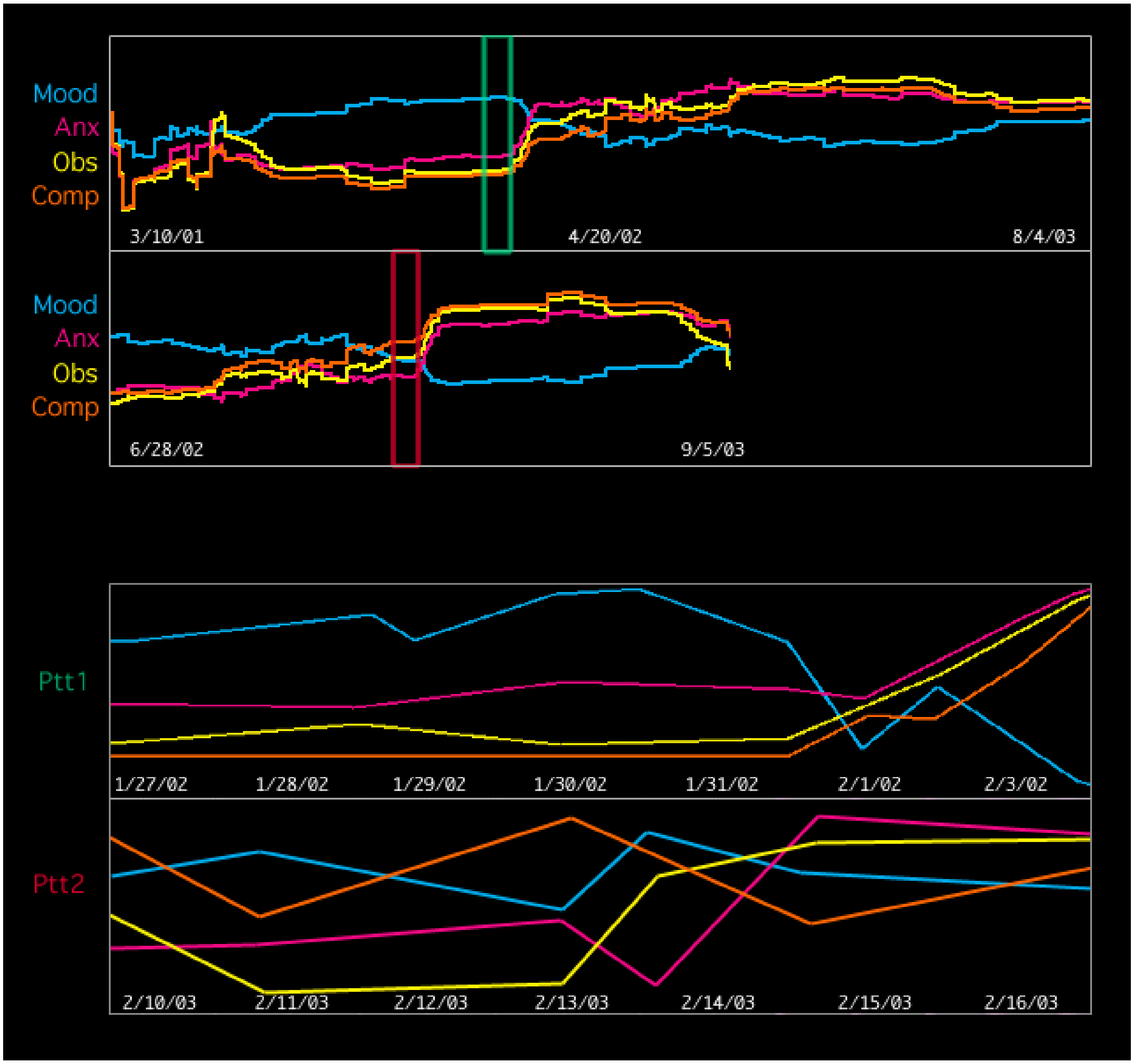

Figure 2: The same interface can be used to compare different time slices between patients. Note the time scales remain consistent across components.

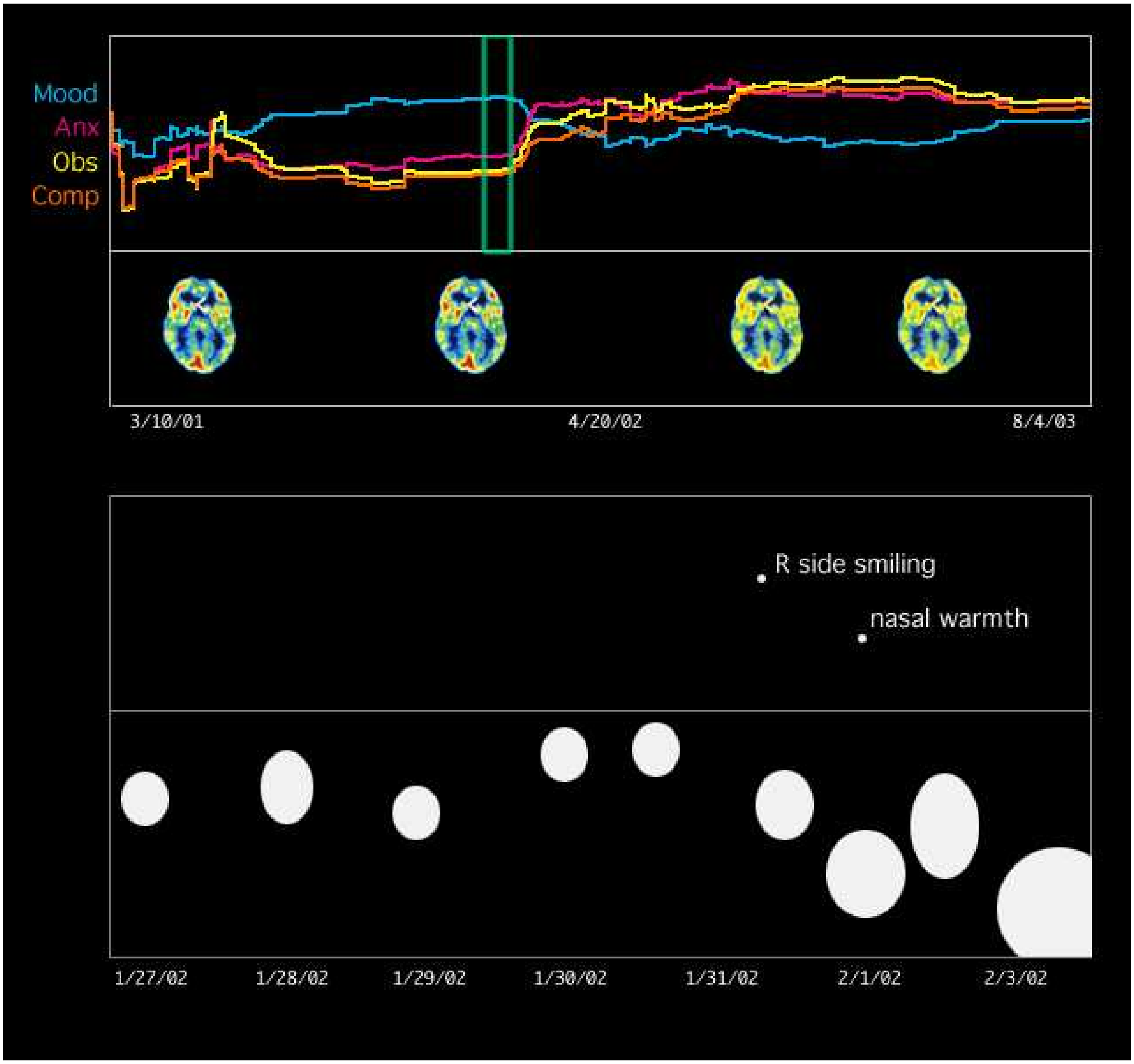

Figure 3: Many different types of data and visualization techniques can be integrated.