Assessing the Role of the Basal Ganglia in Human Decision-Making

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Abstract

Deep Brain Stimulation (DBS), besides an effective therapeutic tool, is a fascinating physiological "window" on human subcortical structures. In fact, local field potential (LFPs) recordings in patients provide an amount of physiological data on basal ganglia, especially in relation to their motor, cognitive and affective functions.

In this study we aimed to assess a novel methodological approach for estimating the functional role of the basal ganglia. In particular, we focus here on decision making processes, by recording the scalp Electroencephalogram and Local Field Potentials oscillations from the Sub-Thalamic Nucleus in patients with Parkinson's disease who underwent neurosurgical procedures for Deep Brain Stimulation. Our results show that STN oscillations is modulated by the execution of gambling task. In particular, this modulation was different from that induced by the execution of a motor control task: whereas the motor task induced a desychronization in the low- and high-beta oscillation (10-20 Hz), gambling tasks synchronized beta activity in both sub-bands.

We conclude that LFPs oscillations provide a direct window on STN activity during decision making. Since LFPs oscillations were differentially modulated by the gambling and motor task, the STN could be involved in a circuit encoding non-motor information during decision making processes.

Keywords: Decision-making; Gambling; Parkinson Disease; Deep Brain Stimulation; Local Field Potentials.

Introduction

Decision making involves different brain structures. Though functional neuroimaging studies provided data on the contribution of several cortical areas, the role of subcortical nuclei in decision-making is still unclear. Yet, patients with subcortical lesions can have impaired decisional processes (Opris & Bruce, 2005). Lesion studies are however difficult to be interpreted, especially for inferring the function of relatively small nuclei as, for instance, the basal ganglia. For the same reason studies of functional neuroimaging of subcortical structures during decision-making have important methodological limitations.

Ideally, the best experimental approach to study the role of subcortical structures during decision-making would be to record neuronal activity directly from subcortical nuclei. The fascinating opportunity to study the electrophysiological correlates of decision making processes in the human basal ganglia is offered by patients undergoing electrode implantation for deep brain stimulation (DBS). DBS treatment is presently indicated for complicated Parkinson's disease, torsion dystonia, tremor, Tourette syndrome, obsessive compulsive disorder (Limousin & Martinez-Torres, 2008; Johnson et al., 2008). After neurosurgical implantation of the electrodes in the basal ganglia, they can be used for few days for recording the local electrical field potential oscillations (LFPs) in the target structure where the electrode is implanted while the

patients is awake and free to move without constraints. DBS, besides an effective therapeutic tool, is therefore a fascinating physiological "window" on human subcortical structures that through Local Field Potentials (LFPs) recordings in patients provided an amount of physiological data on basal ganglia, especially in relation to their motor, cognitive and affective functions. Depending on the condition to be treated, DBS electrode can be implanted in the subthalamic nucleus (STN), in the internal segment of the globus pallidus or in the thalamic nuclei.

In this study we aimed to assess a novel methodological approach for estimating the functional role of the basal ganglia in decision making processes during the execution of the gambling task by recording the scalp Electroencephalogram (EEG) and LFPs oscillations from the STN in patients who underwent neurosurgical procedures for DBS.

Methods

Patients

Five patients (2 females, 3 males) with Parkinson's disease were studied after their informed consent and local ethical committee approval.

Surgical Procedure

All patients were bilaterally implanted in the STN with macroelectrodes for DBS (model 3389 Medtronic, Minneapolis, USA). The STN was targeted by direct visualization through a CT-MRI fusion-based technique before surgery, as detailed elsewhere (Rampini et al., 2003). The site of electrode implantation was then adjusted during surgery with recordings from the explorative microelectrodes (Priori et al., 2003), and by clinically assessing changes induced by stimulation through probe microelectrodes and through the implanted macroelectrodes. Postoperative imaging CT scans were fused with preoperative T2-weighted MRI to assess the final position of the DBS electrode and to verify the consistent placement of contact 1 within the STN (Figure 1).

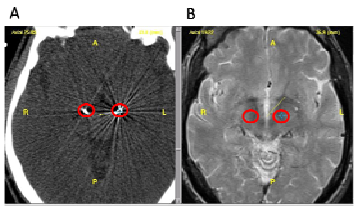

Figure 2: Axial projection of the (A) postoperative stereotactic CT (slice 25 of 85, 43.0 mm) matched with (B) preoperative stereotactic MR (slice 19 of 22, 36.9 mm) of one representative patient. The two red circles represent the electrodes in the two images. The same software used for preoperative planning procedures was used to match the two images.

Experimental protocol

The experimental protocol included two sessions. First, one or two days before surgery, after a brief mood and anxiety evaluation a scalp EEG was recorded while the patient executed the gambling and the motor tasks. Second, two/three days after surgery, the psychological assessment was repeated and LFPs and EEG were simultaneously recorded during the execution of the gambling and the motor tasks. Both experimental sessions were conducted about one hour after patients received their usual dopaminergic medication, to reach the most physiological condition.

Psychological assessment Mood and anxiety (state and trait) were assessed through HAD and STAI (Y-1, Y-2). Mood, anxiety and distress were also subjectively evaluated through three visual analogue scales (VASs). After surgery, patients were re-assessed with STAI Y-1 and VASs.

Gambling tasks Two gambling tasks were administered: a 80/20 and a 60/40. Six different stimulus pairs (AB, AC, AD, BC, BD, CD) were presented in random order, and participants had to choose one of the two stimuli. Feedback followed the choice to indicate the consequent result and the total amount of money accumulated by the subject. In the 80/20 (60/40) task, for instance, the AB pair indicates that a choice of stimulus A led to positive outcome (+60 euros) in 80% (60%) of trials and to a negative outcome (-30 euros) in 20% (40%) of trials, whereas a choice of stimulus B led to negative outcome (-30 euros) in 80% (60%) of trials and to positive outcome (+60 euros) in 20% (40%) of trials. This represents a low conflictual decision context. The BC pair indicates that the selection of stimulus B led to negative outcome (-30 euros) in 80% (60%) of trials and to positive outcome (+60 euros) in 20% (40%) of trials, whereas a choice of stimulus C led to high gain (+100 euros) in 20% (40%) of trials and to a high loss (-70 euros) in 80% (60%) of trials. This represents a high conflictual decision context. Selections and reaction times (RTs) were collected and analyzed.

Motor task To exclude the effect of the pure motor component of the gambling task, a motor task was administered to the subject. Subjects were presented a white circle on a black screen. The circle can appear on the right or on the left of the screen. Subjects were instructed to press as fast as possible the button omolateral to the stimulus, using the right hand for the right button, and the left hand for the left button. Accuracy and RTs were collected and analyzed.

Electrophysiological recordings and analysis During the first session (pre-surgery) scalp EEG was recorded through Ag/AgCl electrodes and following the standard international 10/20 system. EEG were first recorded at rest (3 minutes with eyes closed and 3 minutes with eyes open) to have a basal recording and then synchronized with the execution of the gambling or motor task: when the patient

pressed the response button, a trigger signal was sent to the recording system.

During the second experimental session (post-surgery), subthalamic LFPs and scalp EEG were recorded at rest (basal recording, 3 minutes eyes closed, 3 minutes eyes open) and during the execution of the motor/gambling tasks.

LFPs were captured from the implanted electrodes, before the subcutaneous high-frequency stimulator was connected, while macroelectrodes were still externalized and accessible. The 3389 Medtronic electrode has four cylindrical contacts (1.27 mm in diameter, 1.5 mm in length, spaced 2 mm centre to centre) denominated 0-1-2-3, beginning from the more caudal electrode. According to intraoperative and postoperative tests, contact 1 was consistent with placement within the STN. LFPs were captured from the 3389 electrode using the central closely spaced pair of contacts (contacts 1–2) using a bipolar recording.

Scalp EEG was recorded only from frontal electrodes, namely Fp1, Fp2, F3, F4, F7, F8 of the 10/20 international system because of the presence of wounds from the surgery.

All the signals were captured through the Galileo BE Light EEG amplification system (EBNeuro SpA, Italy), preamplified, differentially amplified, analogically band-passed (2-500 Hz), and digitally sampled at 1024 Hz, with 12 bit quantization with 5V range. All further analysis was conducted off-line with the Matlab software (version 6.5, The Mathworks, Natik, MA, USA).

Quantitative EEG analysis was performed through power spectral analysis and coherence analysis.

STN oscillations at rest were quantified by standard LFPS power spectral analysis.

Spectra were calculated using Welch's averaged, modified periodogram method: signals were divided into segments of 1024 samples, with no overlap; in each segment, the mean was subtracted; each segment was windowed by a Hanning window; the squared magnitude of the discrete Fourier transform of each segment was calculated; and the squared magnitudes of each segment were averaged, to obtain the estimated power spectral density (PSD). The resolution of the calculated spectrum was 1 Hz.

Task-related analysis was performed by averaging the power spectrum over all the trials available (Figure 2). For each gambling trial, the starting point was the stimulus presentation, calculated as the difference between the trigger occurrence time and the reaction time registered by the software and the end point was placed 750 ms after the trigger, at the end of the feedback presentation. For the motor task, the starting point was the stimulus presentation, as in the gambling task, but the end point was 500 ms after the trigger.

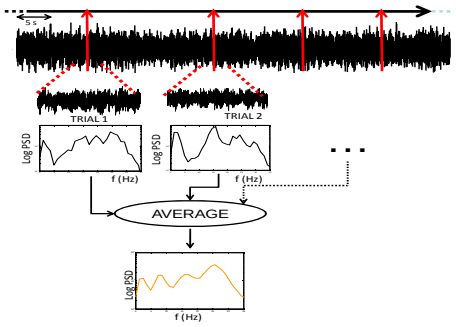

Figure 2: Triggered data analysis.

Results

All the patients had normal mood and anxiety before and after surgery. The performance of motor and gambling tasks before and after surgery did not change. Gambling tasks revealed that patients choose the riskiest and the most conflictual choices.

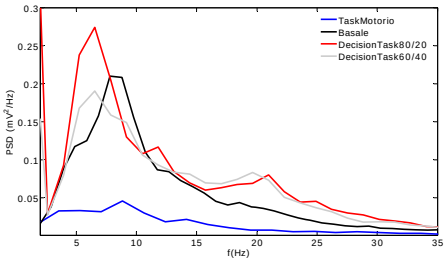

Figure 3: Electrophysiological results. STN-LFPS Power spectra at baseline (black line), during motor (blue line), and gambling (red and grey lines) tasks. X-axis: frequency; y-axis power spectral density (PSD).

STN oscillations were modulated by the execution of gambling task and this modulation was different from that induced by the execution of the motor task: whereas the motor task induced a desycnhronization in the low- and high-beta oscillation (10-20 Hz), the gambling tasks synchronized beta activity in both sub-bands (Figure 3).

Conclusion

We reported here preliminary results about the role of basal ganglia in decision making processes. The possibility to record LFPs oscillations during gambling tasks provides a novel direct window on STN activity during decision making and, more generally, the opportunity to assess its role in complex cognitive processes. This methodological approach might contribute to the analysis of executive functions in human subjects.

The fact that the STN neural activity may be directly recorded and coupled with scalp EEG with high spatial and temporal resolution, may contribute to overcome some important limitations of neuroimaging techniques.

In this preliminary study, STN-LFPs oscillations were differentially modulated by the gambling and motor task. STN could hence be involved in a circuit encoding non-motor information during decision making processes. LFPs oscillations reflect the activity of large populations of neurons and they provide a complex and articulate view of information processing in the brain. Our preliminary data suggest that neural processes underlying gambling involve the STN and, possibly, the whole basal ganglia circuit.

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