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# ELECTROCORTICOGRAPHIC ACTIVITY DURING PERCEPTION AND IMAGINATION OF SOUNDS

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## ABSTRACT

Brain-computer interfaces (BCIs) aim at restoring lost motor functions of paralysed patients by using neuronal activity to control an external effector, like a computer, a robotic arm or a hand/arm prosthesis. Electroencephalography (EEG), a recording technique using electrodes placed directly on the surface of the brain, provides neuronal signals at a higher spatial resolution than EEG by less invasive means than needed for single-unit/local field potential recordings. Using this technique, we investigated whether signals from the human Superior Temporal Lobe might serve as alternative BCI control signals in situations where the motor cortex is not applicable. ECoG activity of two epileptic patients was recorded during perception and imagination of several auditory stimuli. Our results show (i) that perception of different auditory stimuli induces a strong gamma increase over several electrodes, (ii) that this activity differs for different stimuli, and (iii) that auditory imagination produces significant increase of gamma activity over some electrodes. The latter gamma increase suggests that auditory imagination can be used to learn the modulation of brain activity for ECoG-based-BCI control.

## KEY WORDS

Brain-Computer Interfaces, Electroencephalogram, Human Temporal Lobe, Auditory perception, Auditory imagination.

## 1. Introduction

### 1.1 ECoG based Brain Computer Interface

Brain-Computer Interfaces (BCIs) [1-3] aim to enable paralysed patients to operate computers or artificial devices such as hand/arm prostheses by brain activity. Whereas many of today's BCIs are operated through non-invasive recording techniques [3] and are controlled by patients by indirect signals such as modulation of their own brain rhythms, several studies have shown that ECoG recordings constitute a promising technique to build more "intuitive" BCIs [4-7]. Indeed, these studies show that some features of a movement can be directly be inferred from the ECoG

signals that are naturally produced to control movements.

### 1.2 Auditory BCI

Nowadays, most of invasive BCI research is focused on neuronal activity that is generated by motor cortical areas during real movements. Several drawbacks might arise from this approach. First, algorithms that are used to control cursor movement need to be trained using neuronal signals recorded during real or imagined movements. The first procedure would be impossible for paralysed patients. Second, stroke patients may have lesions in motor areas and therefore might not be able to produce movement related-brain signals that are used in this type of BCIs. Finally, it has been reported that motor imagery can be very demanding and difficult for persons who are paralysed for many years. These issues might be overcome by using imagination in other modalities such as visual or auditory imagination. Indeed, it has been shown that with EEG recordings, auditory imagination leads to better discrimination when compared to other cognitive tasks than motor imagination [8]. However, such BCIs do not meet the criterion of being intuitively controlled, in the sense that the cognitive task has a priori nothing to do with motion. One way of building an intuitive auditory BCI would be to use auditory stimuli that are reminiscent of motion. These "moving stimuli" could then be better associated by the subject to cursor movements. For example, a tone moving from right to left for a leftwards cursor movement, or a tone increasing its frequency for upwards cursor movement. Until now, however, it is unknown whether imagination of such intuitive auditory stimuli elicits activity patterns on the level of ECoG recordings. Moreover, it is unexplored whether perception and imagination of the same stimuli evoke similar ECoG activity on the surface of the auditory cortex.

## 2. Methods

### 2.1 ECoG experiments

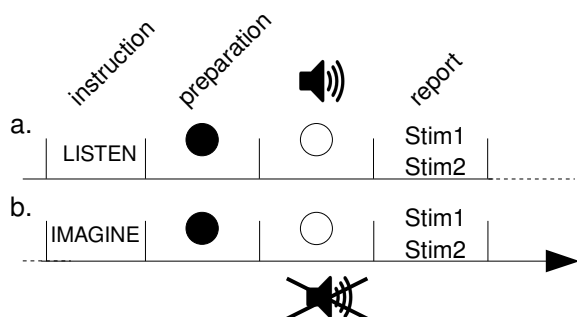
#### *Subjects and recordings*

Two patients suffering from intractable pharmaco-resistant epilepsy were included in the study after

having given their informed consent. Stainless steel electrodes grids (8\*7 for subject S1 and 8\*4 for subject S2) were subdurally implanted over superior temporal lobe of the right (S1) or left hemisphere (S2) for pre-neurosurgical epilepsy diagnosis. The site of electrode implantation was exclusively based on the requirements of the clinical evaluation. None of the subjects reported known hearing problems. The study was approved by the University Clinic's ethics committee.

### Task

The task contained two types of trial blocks (Fig. 1). In perception blocks, subjects were explicitly asked to listen to the upcoming stimuli through an instruction written on a computer LCD screen. Within each block consisting of six trials, two stimuli were presented randomly with equal probability (Fig. 1a). After stimulus presentation subjects reported which stimulus they heard by a button press. Imagination trials (Fig. 1b) were exactly as perception trials except that the instruction was to imagine one of two stimuli that were presented during the last listening block. Perception and imagination blocks were alternatively presented and a session was over after 108 blocks of each type. The first patient underwent two sessions, the second patient three sessions. After the whole experiment the vividness of the auditory imagination was assessed by asking the subjects to rate the vividness on a scale from 1 (no perception at all) to 5 (perfectly clear, imagination as vivid as normal perception).



**Fig 1.** Description of the task.

### Stimuli

Six different stimuli were used in this study: two frequency modulated tones linearly rising (or falling) from 60 Hz to 1200 Hz (and vice versa); two pure tones with a phase-shift between the stereo outputs generating the perception of a sound moving from right to left (and vice versa), and two natural sounds, one consisting of a German sentence pronounced by a male speaker in quiet and a birdsong recording. All stimuli lasted two seconds.

## **2.2 Data analysis**

### Preprocessing

Electrocorticograms (ECoGs) were digitized at either 256 Hz (S1) or 1024 Hz (S2) sampling rate using a

clinical AC EEG-System (IT-Med, Germany). All signals were re-referenced by using a common-average reference.

### Time-frequency analyses

Time-resolved fast Fourier transformations were applied with Hamming windows. Normalized power spectral densities were computed by normalizing each frequency bin by the respective power during spontaneous activity taken between 1.5 and 0.5 sec before stimulus onset. Stimulus-by-stimulus analyses were conducted by computing the averages and standard errors of the normalized high gamma frequency (40-120 Hz) across all trials of the given stimulus (either perceived or imagined).

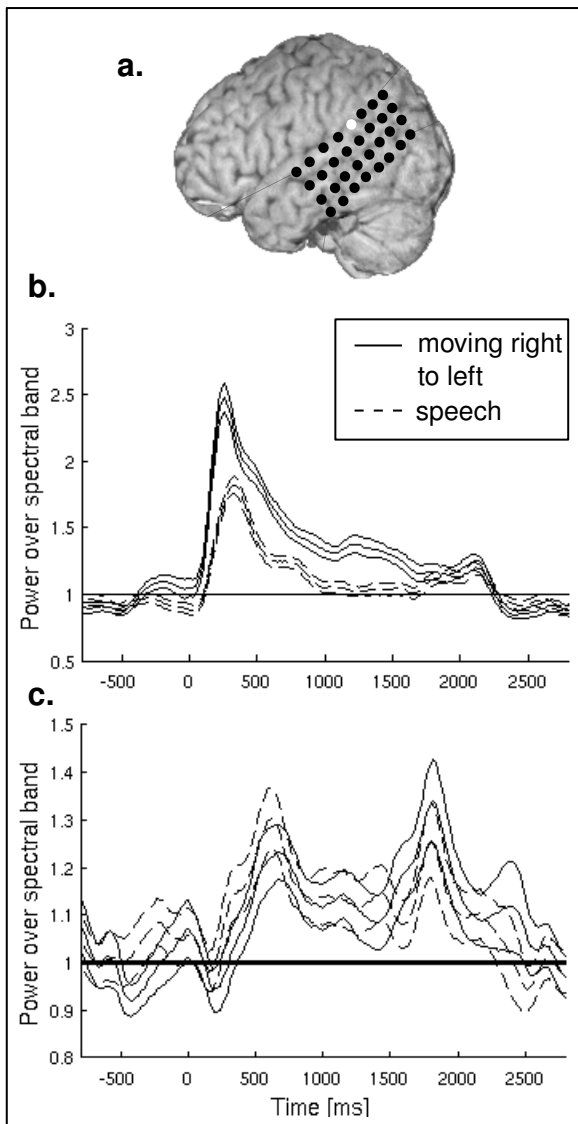
## **3. Results**

### **3.1 Auditory Perception**

When ECoG signals were averaged across all stimuli, four (S1) to five (S2) electrodes showed a large stimulus evoked power increase in the gamma and high-gamma frequency range (40-120 Hz) starting between 100 and 250 msec after stimulus onset. Depending on the location of the electrode, this gamma activity increase lasted either during the whole stimulus or vanished soon after it started. A comparison within the stimulus set revealed that the spatio-temporal distribution of gamma activity across electrodes was different for the natural and the artificial stimuli for both patients. Moreover, for some particular electrodes, it appeared that the time course of gamma activity largely differed from one stimulus to another (Fig. 2b).

### **3.2 Auditory Imagination**

Auditory imagination trials were averaged across all stimuli in order to determine whether imagination evoked activity as compared to baseline. For both patients, some of the electrodes showing increased gamma activity during perception also showed increased gamma activity during imagination. (Fig. 2c) The activity increase during imagination was generally substantially smaller than during perception. A stimulus by stimulus analysis revealed that, on average across trials, gamma activity evoked by imagination was not stimulus dependent even though both subjects reported a relatively high vividness of imagination for most stimuli (mean: 4.12 on a scale from 1 to 5, standard deviation: 1.09).



**Fig 2.** (a.) Location of the ECoG grid and of the specific electrode shown in b and c (thick white point), (b.) Average power over [40-120] Hz spectral band ( $\pm$  standard error of the mean) during perception of the moving right to left stimulus (full line) and the speech (dashed line) and (c.) during imagination of the same stimuli. Power is relative to a baseline epoch (1500-500 msec before trial start).

#### 4. Conclusion

In summary, our results show that it is possible to discriminate perceived sounds from ECoG gamma activity recorded from the superior temporal lobe. The imagination of sounds also produced a significant increase in the same frequency range but stimulus independent. This general gamma response evoked by auditory imagination might be used to learn the modulation of brain activity for BCI control [9]. To facilitate a sound specific neuronal response during auditory imagination – as required for the described intuitive approach – future investigations might e.g. (i) provide feedback to the subject whenever he imagines a sound, (ii) use a more extensive presentation of the

different stimuli beforehand, (iii) apply an optimized set of sounds which can be imagined more specifically and/or (iv) record from ECoG grids with higher spatial resolution.

#### Acknowledgements

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