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Special issue: Editorial

What does human intracerebral recording tell us about emotions?

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Most emotion theorists agree that emotions are episodes of synchronized or concomitant changes in several of the organism's components including physiological arousal, motor expression, subjective feeling, as well as, according to some researchers, action tendencies and cognitive processes (or "appraisals"). These changes occur in response to events of major significance to that organism; events which may be either internal, taking the form of thoughts or memories, or external, such as other people's behavior, a change of situation or an encounter with a novel stimulus (Grandjean, Sander, & Scherer, 2008; Grandjean & Scherer, 2008; Sander, Grandjean, & Scherer, 2005; Scherer, 1984; Scherer, Schorr, & Johnstone, 2001). Affective neuroscience is concerned with identifying the neural bases of these emotional processes (Davidson, 2009), understanding the mechanism and dynamics of the human affective brain and, where possible, exploiting this understanding to develop methods to repair its disorders or malfunctioning. The electrical activity of brain cells is a key feature of this mechanism but, for ethical reasons, scientists rely mostly on animal research to explore it. Research in humans is often limited to the electrical signals that can be recorded at the scalp, or else to surrogates of electrical activity namely magnetic source, blood oxygenation and flow, or molecular imaging. As superbly described and reviewed by Mukamel and Fried (2012), there are also rare and precious opportunities for record the activity of single brain cells and small cellular assemblies in awake humans. These recordings provide a unique insight into aspects of how human cognition can emerge from neuronal assembly activities that are impossible to study in animals, including, for example, high-level integrated processes. In recent decades, the direct study of brain tissue in the awake human has been made possible by the synergistic work of neurosurgeons, neurologists, psychologists, neuroscientists, and engineers, sustained by the dramatic and continuous development of new technologies and computing resources. These developments allowed researchers to characterize high-level cognitive processes using intra-cerebral recordings at unprecedented temporal and spatial resolutions. This technique has already led to a better understanding of functions such as perception, language, sleep, action, or memory. In this Special Issue, experts document its contribution to the understanding of one of the most integrated and complex human abilities, namely emotional processes.

Intracranial electroencephalography (iEEG) consists in recording *in situ*, and thus invasively, the electrical activity of single neurons (multi-unit action potentials) and/or groups of neurons (local field potentials) through electrodes placed directly in brain tissue. In humans, some diseases of the central nervous system may require the placement of electrodes on the surface of the brain, or their implantation deeper within it. For instance, electrodes may be implanted in the context of deep brain stimulation, a technique used to stabilize the symptomatology of movement and affective disorders (e.g., Parkinson's disease, Gilles de la Tourette syndrome, obsessive-compulsive disorder, depression) but also for cognitive enhancement in memory impairment. The electrodes may also be implanted for the purpose of stereo-electroencephalography in patients with drug-resistant epilepsy, in order to investigate the electrical activity of areas of the brain where resection could subsequently be performed (see Mukamel & Fried, 2012 for an exhaustive review of the clinical contexts of such recordings as well as the advantages and limitations of iEEG to study high-level cognitive processes in humans). iEEG provides a unique opportunity for studying the temporal dynamics of cognitive and emotional processes, as it combines the excellent temporal resolution inherent to electrophysiological methods with high anatomical

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resolution. This technique also allows scientists to measure both local and distant functional and effective connectivity in a dynamic and selective way.

In this context, the aim of this Special Issue is to describe and discuss how iEEG can help cognitive neuroscientists, psychologists, and neurologists understand the neural basis of emotion processing in humans. A second aim of this Special Issue is to discuss how iEEG can be used to assess emotional disturbances in specific central nervous system pathologies such as neuropsychiatric disorders or Parkinson's disease.

The present Special Issue brings together studies that explore intracerebral electrophysiological activity during emotion processing in its very broadest sense. It opens with two reviews. The first one, by Frisaldi and colleagues (in the current issue), deals with the placebo effect through single-neuron recordings in Parkinson's disease patients, underlining the need to control for expectations when performing such recordings in awake humans. The second review, by Murray and colleagues (in the current issue), presents the previous literature on human amygdalar intracerebral recordings and emotion processing (see Mukamel & Fried, 2012 for a review of other structures than amygdala iEEG recordings and emotion; see also Péron, Frühholz, Vérin, & Grandjean, 2013 for a review of human subthalamic nucleus iEEG and emotional processing). The Special Issue then looks at iEEG results in the context of face recognition (Müsch et al., and Sato et al., in the current issue), subjective feelings (Huebl et al., Liegois-Chauvel et al., and Wojtecki et al., in the current issue), decision making (Siegert et al., in the current issue), and appraisals (Bastin et al., Singer et al., and Lipsman et al., in the current issue). These contributions highlight the usefulness of this method for understanding the neural circuits and dynamics of emotions in humans, but also discuss its challenges, limitations, and possible future developments.

This topic is particularly timely, given that new targets for deep brain stimulation in neuropsychiatric disorders have recently been identified, allowing researchers to study the neuronal dynamics of structures known to be involved in emotion processing. In this context, new opportunities for recording signals within the human brain are expected to emerge in the near future, including innovations in deep brain stimulation and in the field of brain-machine interfaces. In clinical terms, the present field of research has the potential to bring about very real improvements in the quality of life of recipients of deep brain stimulation. For example the electrophysiological signature of the non-motor effects of DBS could be used as a biomarker in the future development of so-called "smart", *closed-loop* deep brain stimulation devices, which, in addition to stimulation, would allow for the simultaneous measurement of electrical activity in the target area. Some groups are currently seeking to devise systems that would automatically adjust their deep brain stimulation output as a function of measured electrical activity, the aim being to maintain adequate neuronal oscillations in the brain. The research exposed in the present Special Issue will enhance our understanding of patients' brain activity during the performance of emotional tasks, and thus inform research on this new generation of deep brain stimulation devices, particularly for affective disorder populations.

According to the multi-componential view of emotions, which provides the frame for this Special Issue, affective phenomena and, more specifically, the emergence of feelings, can be regarded as a psychological system of synchronized rhythms from simple to complex dynamics. iEEG is particularly suitable for studying the brain dynamics of these phenomena which constantly shift from the complex to the predictable (Friston, 2000a, 2000b, 2000c). Accordingly, we would like to conclude this editorial by quoting Jorge Luis Borges, as György Buzsaki (2006) did before us to poetically illustrate his conception of *systems of rhythms*: "Ts'ui Pên … did not think of time as absolute and uniform. He believed in an infinite series of times, in a dizzily growing, ever spreading network of diverging, converging and parallel times. This web of time – the strands of which approach one another, bifurcate, intersect, or ignore each other … – embraces every possibility." (Jorge Luis Borges, *The Garden of Forking Paths*).

This Special Issue is intended to provide a snapshot of an emerging realm of investigation that promises to open up thrilling and fascinating avenues of research, both *basic* and *applied*.

Geneva, September 1st 2014

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