

Consciousness and unconsciousness: an EEG perspective

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At first glance, defining unconsciousness may seem easier than defining its counterpart consciousness. Indeed, consciousness has many definitions¹, while unconsciousness is “just” the absence of consciousness. However, the study of patients with epilepsy or severe disorders of consciousness (e.g., coma and vegetative states) or focal deficits of consciousness (e.g., blindsight) and studies on sleep and anesthesia have shown that consciousness and unconsciousness are graded. Measuring consciousness or its gradation is essential but there is little consensus on how it should be done. Different behavioral and neurophysiological measures of consciousness and theories of consciousness have been proposed (e.g., higher order thought theories, integration theories, and worldly discrimination theory²). In clinical settings, the differentiation between consciousness and unconsciousness is limited to evaluating patients’ motor responsiveness. This is extremely challenging because some patients are paralyzed (e.g., during anesthesia or following severe acute brain damage) or may be deprived of the capacity to make normal physical movements. Aphasia, apraxia, and cortical deafness or blindness are other possible confounders. Clinical studies have also shown how difficult it is to differentiate reflex from voluntary movements³. Furthermore, besides the diagnostic problems (“Is the patient conscious?”); the problems of quantifying the level and content of consciousness, (“What is she/he conscious of?”) we need to tackle the prognostic challenges (“Will the patient ever recover consciousness?”).

In addition to standardized clinical evaluations, electroencephalography (EEG) recordings have been assessed as objective markers of consciousness⁴. Routine clinical EEG allows the physician to monitor the brain’s background electrical activity and possible seizures. To unravel physiological or pathological events, clinical EEG often involves provocative tests such as photic, auditory or painful stimulation. Reactivity of the brain to these external stimulations can be observed in unconscious brain damaged patients and has good prognosis value^{5,6}. Small changes induced by sensory or cognitive activities may be observed with event related potentials (ERP). Short latency ERPs reflect activation in low-level sensory receptive structures of the brain. They have good prognostic value in comatose patients (for review see Vanhaudenhuyse et al., 2008⁷). ERPs obtained after 100 ms of the presentation of a stimulus assess cognitive functions and are influenced by the level of attention and consciousness. Recently, ERP paradigms based on active participation of the subject, e.g., counting deviant

stimuli, have been proposed to help detecting signs of consciousness (i.e. command following)⁸⁻¹⁰.

With the advent of digital EEG technology, the computation of complex parameters has been made possible leading to a quantitative analysis of the EEG signal. Parameters based on EEG complexity and connectivity permit to quantify the effects of anesthesia in the operating room. They have also been tested in sleep and disorders of consciousness¹¹. Correlated activities among brain areas or electrodes can determine patterns of functional connectivity which is known to be impaired in anesthesia, sleep or disorders of consciousness, or to be paradoxically increased during epileptical activity¹². Connectivity and complexity measures are being validated as quantitative measures of consciousness¹³⁻¹⁶. In line with these measures, the recently proposed Perturbational Complexity Index (PCI,¹⁷) based on simultaneous transcranial magnetic stimulation (TMS)-EEG recordings permits to stereotactically perturb the cortex to engage distributed interactions and measure the information content (algorithmic complexity) of the resulting EEG responses.

The present special issue summarizes and updates recent research and clinical findings with regard to the application of EEG techniques to measure the level of consciousness. Noirhomme and colleagues propose an automatic quantification of background EEG and reactivity in comatose patients treated by hypothermia and relate their measure to the prognosis of the patient. Next, Lugo and colleagues present a novel approach to test response to command in patients with locked-in syndrome based on an active vibro-tactile ERP oddball paradigm. Marchant et al. review the current use of EEG to monitor anesthesia. Marinazzo and colleagues tackle the problem of connectivity measures in patients with disorders of consciousness with an innovative approach based on transfer entropy and calculations imported from economy theory. Sarasso and colleagues use TMS-EEG and the PCI to measure consciousness in brain-damaged patients with altered states of consciousness. Finally, with the paper of Gaillard et al., we take a step back from EEG and neurophysiological measures to review the difficulties related to behavioral measures of consciousness using explicit and implicit learning as an example.

As you will read in the present volume, research on consciousness remains very challenging but has been making impressive recent advances and electrophysiological studies take an important part in these progresses. Results from the presented and ongoing research will have a major influence on the clinical care of patients with disorders of consciousness or those undergoing anesthesia but will also improve our knowledge on the neural correlates of consciousness.

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