Quantitative EEG in Consciousness Disorders

Subjects: Neurosciences
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The role of quantitative EEG technology in the diagnosis and prognosis of patients with unresponsive wakefulness syndrome and minimally conscious state.

Keywords: unresponsive wakefulness syndrome ; minimally conscious state ; EEG ; quantitative EEG ; disorders of consciousness ; diagnosis ; prognosis

1.Introduction

In recent years, neurological intensive care and medical care in general have improved substantially. Hence, more people are surviving severe brain injuries. Thus, the percentage of people dying from traumatic brain injuries, for example, decreased from 16% in 2000 to 11% in 2010 [1]. Nevertheless, not all people fully recover, and many patients remain in a prolonged coma, defined as a state of absence of arousal (eye opening) and awareness (non-reflexive behavior or command following) [2], in the acute state, and a substantial number (10–15% [3]) of survivors stay with disorders of consciousness (DOC). DOC describe a continuum of states with no arousal or awareness to states of full arousal and awareness. Patients with DOC are categorized as being in one of three main states: (i) coma, (ii) unresponsive wakefulness state (UWS) and (iii) minimally conscious state (MCS) [4]. Patients in UWS open their eyes spontaneously but are unresponsive to external stimuli or show just reflex movements, see, e.g., [5][6][7][8]. Patients with MCS, in contrast, show evidence of awareness of themselves or of their environment, though this awareness fluctuates [4]. MCS plus (MCS+) patients show high-level behavioral responses, namely, command following and intelligible verbalization, or non-functional communication. On the other hand, MCS minus (MCS−) patients only show low-level behavioral responses. These may include visual pursuit, the localization of noxious stimuli or appropriate crying or smiling when exposed to emotional stimuli [9]. Patients that regain consciousness after being in MCS are referred to as being in emerging MCS (EMCS), i.e., they are already able to functionally communicate and functionally use objects [10]. Moreover, on the upper boundary of MCS, there is severe neurocognitive disorder (SND). Those patients show evidence of arousal and awareness, i.e., consciousness, but have severe impairment to two or more cognitive sub-functions [11]. Another state which must not be confused with DOC is the so-called locked-in syndrome (LIS). In contrast to patients with severe disturbances of consciousness, patients with LIS are aware of themselves and their environment but are fully de-efferentiated, due to bilateral transection of pyramidal tracts at the level of pons or cerebral peduncles, leading to complete immobility except for vertical gaze [2]. Some studies included conscious subjects (CS), i.e., patients with brain injuries who are fully conscious, e.g., [12].

Over the years, various scales have been introduced to categorize DOC patients, see, e.g., [13] for a review. The Glasgow–Liège Scale (GLS), which was introduced in 1982, is a combination of the Glasgow Coma Scale (GCS) [14] and quantified analysis of brain stem reflexes [15]. Moreover, there is the Innsbruck Coma Sale (ICS), which is similar to the GCS and also has number of separate assessments which are added up to an aggregate score [16]. The Wessex Head Injury Matrix (WHIM) was developed for assessing and monitoring patients' recovery after severe head injury [17]. The state-of-the-art scale to assess coma in the non-emergency setting today is the JFK Coma Recovery Scale-Revised (CRS-R) [18], which is based on the Disability Rating Scale (DRS) [19] and the Coma Recovery Scale (CRS) [20]. The Coma/Near Coma (CNC) Scale is, similar to the DRS, related to the patient's status, course and outline, but also to the underlying electro-neuro-physiological dysfunction [21].

The American Academy of Neurology and the American Clinical Neurophysiology Society define quantitative EEG (QEEG) as: "… the mathematical processing of digitally recorded EEG in order to highlight specific waveform components, transform the EEG into a format or domain that elucidates relevant information, or associate numerical results with the EEG data for subsequent review or comparison" [22]. It involves the use of computers, and several measures, e.g., the power spectrum, can be derived from it. In this review, we will critically assess the role of QEEG in the diagnosis and prognosis of patients with DOC. We will focus on QEEG because it is, other than functional magnetic resonance imaging (fMRI) or positron emission tomography (PET), non-invasive, less expensive, widely applicable and a bedside measurement.

2. Behavioral Test

Behavioral tests are the gold standard for diagnosis and the following prognosis, even though they have limitations [23]. Hence, clinicians and neuroscientists often seek for additional tests to behavioral tests. Here, we review the current literature on diagnosis and prognosis of DOC patients and attempt to give the reader an overview of the parameters that can be extracted from EEG and their usefulness. Our focus lies on the diagnosis and prognosis of DOC patients, since those are the two most important factors for clinical use. Diagnosis is the first step in clinic decision making, on which the choice of treatment is based. The right treatment can just be found with the right diagnosis at hand. Prognosis is important for ethical reasons and especially of interest to the relatives of the patients. Hence, we provide an overview of the research over the last 20 years (2000–2020) of all the different parameters extracted from EEG recordings used for diagnosis and prognosis, and we summarize our findings in two tables at the end. Some existing reviews just focus on prognosis [24] or just present work conducted on resting-state EEG [25], [26]. Other reviews focus on BCI [27] or also EEG reactivity and transcranial magnetic stimulation (TMS)-EEG [28][29]. Another review on EEG and neuroimaging can be found, e.g., in [30]. Moreover, there are also some reviews focusing on interventions and therapy [31][32]. We did not include any of the other mentioned topics, except diagnosis and prognosis, because we intended to write a focused review with just the two most important aspects for clinical practice, and including all mentioned aspects would go beyond the scope of our discussion.

3. Conclusion

In this narrative review, we discussed different metrics that can be extracted from EEG. However, not all of these measures have been equally well investigated and, thus, not all of them can be immediately clinically applied. The measures that are most often reported are alpha and delta power. These are easy to calculate and seem to provide conclusive results and as such should be brought into clinical practice. The theta band, even though often reported, does not seem to provide any conclusive results and as such should be investigated in further studies before bringing it into clinical practice. Sleep EEG is often used and reveals consistent results. The P300 is another measure that should be used in clinical practice because several papers are published on this topic with matching results.

What also has to be kept in mind is that the sample size of the different papers varies a lot. This means that not all results are equally trustworthy. The results of studies which include more subjects and have smaller confidence intervals for their parameters can be seen as more reliable, whereas studies with small sample sizes or large confidence intervals need to be treated with caution.

Concluding our review, we can say that the diagnosis and prognosis of DOC patients are still very difficult tasks. However, QEEG, especially resting-state analysis and sleep patterns, should become a part of the daily routine when treating these patients because it is easy to measure and provides conclusive results.

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