The Impact of Contemporary Neurotechnology on Diagnosing and Treating Patients with Disorders of Consciousness - A Review

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Abstract

Disorders of consciousness, especially Vegetative State, are assessed from a theoretical (historical and ethical) and empirical (neuroscientific) points of view, through a review of the most relevant recent literature.

Both the potentiality of neuroscientific investigation and the limitations of its clinical (diagnostic and prognostic) application are underlined, showing the urgency of a collaboration between science, law and ethics in order to define the most appropriate nosography and to ensure the best therapy to patients with disorders of consciousness.

Keywords: Bioethics; Disorders of Consciousness; Unresponsive Wakefulness Syndrome; Vegetative State.

Introduction

Disorders of consciousness (DOCs) include different severe brain injuries which are assessed through specific diagnostic criteria, mainly by accurate clinical behavioral scales (e.g., Coma Recovery scale-revised, Sensory Modality Assessment and Rehabilitation Technique, Full Outline of Unresponsiveness, Glasgow Coma Scale). The data emerging from such assessment at the bedside could and should be confirmed by new medical technologies, especially electrophysiology and functional neuroimaging. To date through the combination of behavioral and instrumental assessments of consciousness it is possible to distinguish the following severe brain damages or DOCs:

1. Coma
2. Vegetative state (VS) or post-coma unresponsive ness (PCU) or unresponsive wakefulness syndrome (UWS) [1]
3. Minimally conscious state (MCS), recently sub-categorized in MCS+ and MCS- [2]
4. Locked-in syndrome.

The new neurotechnological clinical tools are increasing showing the limitation of the assessment of re-sidual consciousness of patients with DOCs at the bedside, because the underlying neurological condition is often too difficult or even impossible to understand from the behavior. Does this mean that in the case of patients with DOCs the instrumental assessment of consciousness will completely replace the behavioral assessment? How would this hypothetical replacement affect the diagnosis, the management and the therapy of such patients? An overview of the most recent scientific studies, particularly regarding vegetative state, could help us to underline both the opportunity and the issues emerging from neurotechnologies applied to patients with DOCs and to point out the possible consequences for a new nosography.

Historical Perspective

The term “coma” derives from the ancient Greek χώμα (“hair”). In Latin (“coma”), as well as in ancient Greek, the term indicates a state of sleep from which one may not wake up.

The word is used by Hippocrates (460 BC – 370 BC) in his “Corpus” and by Galen (129 AD – 199/217 AD). After these and other historical testimonies in the Greek and Roman age, the notion was rarely mentioned in the literature up to the Seventeenth century [2].

In 1672 Thomas Willis mentioned coma, lethargy, carus (deprivation of sense) and apoplexy in “De ani ma brutorum”.

During the Eighteenth century, the term “coma” is re-current. For example, Herman Boerhaave (1668-1738), in his authoritative lectures, compared disorders of consciousness to sleep and studied intoxications and other possible causes of coma. In the same period, François Boissier Sauvages de la Croix (1706-1767) classified “comate” and several conditions of sound sleep as one class among a series of disabilities.

In the Nineteenth century, with the improvement of medical knowledge, many causes of coma were described [3]. Physical examinations and a series of observations were used for the
In 1899 W. Rosenblath, in the “Archives of Medicine”, described the “Low-Level Neurological State” giving the example of a severe traumatic brain injury occurring to a young acrobat [4].

In the first decades of the Twentieth century the subject was almost completely ignored in the medical literature.

From the 1940s, several case reports were published. In 1940 E. Kretschmer coined the expression “apalic syndrome” (“Das Apallish Syndrome”) [5] to describe the state intervening in case of loss of bihemispheric/cortical functions with concurrent preservation of brain stem functions. The expression spread quickly and was adopted for a long time, thanks also to the noteworthy book “Das Traumatisch Apallische Syn-rome” by F. Gertensbrand [6]. The expressions “Kretschmer syndrome” and “neocortical death” were used as synonyms of “apalic syndrome”. These expressions, now abandoned, are not clinically correct: functional magnetic resonance has demonstrated neocortical areas active in subjects previously classified as in “neocortical death”.

In 1963 M. Arnaud and colleagues used for the first time the expression “vegetative state” (in French: “vie vegetative”) [7].

In 1972 D.H. Ingvar and A. Brun suggested to replace the expression “apalic syndrome” with the expression “disapalic syndrome” or “incomplete apalic syndrome”, since clinical conditions of subjects in such state do not correspond exactly to the conditions caused by the absence of pallium.

The same year the Scottish neurosurgeon B. Jennet and the American neurologist F. Plum attempted to face the confusion in terminology and introduced the notion of “persistent vegetative state” to indicated subjects who come out from coma and remain in condition of “wakefulness without awareness” [8]. The expression “persistent vegetative state” had a world-wide diffusion. For some years, the French school continued to prefer “vigilant coma” (“coma vigil”), but afterwards accepted the expression suggested by Jen-net and Plum. According to the Oxford English dic-tionary, “to vegetate” means to “live a merely physical life devoid of intellectual activity or social intercourse” and “vegetative” describes “an organic body capable of growth and development but devoid of sensation and thought”. To lay public and media, however, it has a rather pejorative undertone and seems, incorrectly, to refer to patients as being vegetable-like. Therefore, the expression had an unintended denigrating connotation.

In 1980 F. Plum and J. B. Posner published the exten-sive study “Diagnosis of stupor and coma”. The book united for the first time a theoretical understanding of the arousal system in the upper brain stem with clin-icopathologic case studies, and in doing so created the modern examination for coma that is based on the patient’s pupils, eye movements, and breathing patterns. In 1989 the American Academy of Neurology published the “Position statement: certain aspects of the care and management of profoundly and irreversibly paralyzed patients with retained consciousness and cognition. Report of the Ethics and Humanities Sub-committee of the American Academy of Neurology” [9].

The description of “vegetative state” adopted by the American Academy of neurology is similar to the definition adopted in 1994 by the The Multy-Society Task Force on PVS (MSTF). According to the MSTF “The vegetative state is a clinical condition of complete unawareness of the self and the environment, accompanied by sleep-wake cycles, with either complete or partial preservation of hypothalamic and brain-stem autonomic functions. In addition, patients in a vegetative state show no evidence of sustained, reproducible, purposeful, or voluntary behavioral responses to visual, auditory, tactile, or noxious stimuli; show no evidence of language comprehension or expression; have bowel and bladder incontinence; and have vari-ably preserved cranial-nerve and spinal reflexes. We define persistent vegetative state as a vegetative state present one month after acute traumatic or nontraumatic brain injury or lasting for at least one month in patients with degenerative or metabolic disorders or developmental malformations. The clinical course and outcome of a persistent vegetative state depend on its cause. Three categories of disorder can cause such a state: acute traumatic and nontraumatic brain injuries, degenerative and metabolic brain disorders, and severe congenital malformations of the nervous system” [10,11]. The notion of “persistent vegetative state” adopted by the MSTF rose much controversy both for clinical and ethical reasons. Nevertheless, it was adopted also by Ethics Committees: the same year the Medical Ethics Committee of the British Medical Association published the “BMA guidelines on treatment decisions for patients in a persistent vegetative state” [12].

In 1996 a working group by the Royal College of Phys-sicians published the report “The permanent vegetative state” in which it distinguished “persistent vegetative state” from “continuous vegetative state” [13].

In 2010 the European Task Force on Disorders of Consciousness (ETFDC) has proposed to replace the name “Vegetative State”, considered not appropri-ated given the clinical condition of the patient showed by instrumental assessment, with the “Unresponsive Wakefulness Syndrome” (UWF) [1].

**Recent Findings From Contemporary Neuroscience**

As the history of their investigation shows, DOCs are surely one of the most problematic and intriguing field of contemporary neuroscience: the astonishing progresses of their assessment during the last decades leave still unanswered important questions. This un-certainty has not only theoretical, but also clinical and medical consequences, so that neuroscientific un-certainty about DOCs, especially about VS, has relevant ethical and legal implications.

As recently outlined [14], to date we know quite a lot about the neuropathology underlying VS but our un-derstanding is incomplete. VS can be clinically defined as wakefulness without awareness: the definition by MSTF states that VS patients show no evidence of sus-tained, reproducible, purposeful, or voluntary behavioral responses to visual, auditory, tactile, or noxious stim-uli; show no evidence of language comprehension or expression; have bowel and bladder incontinence; and have vari-ably preserved cranial-nerve and spinal reflexes [10,11].

This definition has been followed by many other documents. A significant synthesis of the different approaches to VS is the cited Royal College of Physicians definition, according to which VS is a clinical condition of unawareness of self and environment in which the patient breathes spontaneously, has a stable circulation, and shows cycles of eye closure and opening which may simulate sleep and waking [13].
From these definitions three characteristics of VS emerge: cycles of eye opening and closing, giving the appearance of sleep-wake cycles; complete lack of self- and environment-awareness; complete or partial preservation of hypothalamic and brain stem autonomic functions.

35 years after the definition by MSTF, the ETFDC has recently proposed the new label “Unresponsive Wakefulness Syndrome”. According to the ETFDC the main reason to propose a new name for VS is the persistent, even if unintended, negative connotation of the expression “vegetative state”.

The reason for choosing the name VS was to refer to the preserved vegetative nervous functioning (e.g., sleep-wake cycles, respiration, digestion or thermoregulation). Yet the definition of such patients as vegetative has not been universally accepted in these years [15,16,17]. As a result the discussion is open about the appropriateness of the term [18].

Another problematic point is the use of “state”, that, according to ETFDC, risks to suggest chronicity, while a vegetative state may become chronic (lasting for decades) or may remain a transitory condition on the way to further recovery [1,19].

For these reasons the Aspen Neurobehavioral Conference Workgroup has recently proposed the definition of Minimally Conscious State (MCS) to denote the clinical condition of patients recovering from VS and showing more than reflex motor behavior but failing to show functional communication or object use [20]. Furthermore the clinical condition of MCS has been recently subcategorized on the basis of the complexity of patients’ behavior. More specifically MCS+ shows command following, intelligible verbalization or gestural or verbal yes/no responses; MCS shows minimal behavioral interaction with non-reflex movements such as: orientation of noxious stimuli, pursuit eye movements in direct response to moving or salient stimuli; movements or affective behaviors in appropriate response to relevant environmental stimuli [21].

Some have criticized the introduction of MCS because both VS and MCS patients are hopelessly brain damaged [22]. Yet recent findings show difference in neural response to external stimuli [23,24,25] and in prognosis [26,27].

Thus the differentiation between VS and MCS is clinically very important, both for diagnosis and prognosis, so that a big problem of misdiagnosis exists [28,29,30], despite the publication of guidelines about the diagnostic criteria for MCS [30]. According to Grossesries et al. [31], this problem of misdiagnosis illustrates the need for standardized ‘consciousness-scale’. Regarding this point, in a recent milestone paper, the American Congress of Rehabilitation Medicine conducted a systematic, evidence-based review of behavioral assessment scales for disorders of consciousness and provided evidence-based recomm-endations for clinical use founded on content validity (i.e., enclosing diagnostic criteria), reliability, diagnostic validity, and ability to predict functional outcomes [32]. Yet recent neuroscientific findings suggest the need for motor-independent signs of awareness derived directly from brain signals.

From the above summarized studies we can conclude that recent neuroscientific findings suggest to clinicians to be very careful in their conclusions about the awareness of patients with DOCs [14,33-38]. Besides these consequences for diagnosis, rec-cent advancements in neuroscience have an increasing impact on treatment. Particularly “the existing thera-peutic nihilism in the field of DOC is currently get-ting challenged by recent data supporting that some DOC patients could benefit from some rehabilitative interventions (surgical, pharmacologic, or behavioral)” [39]. Furthermore recent new findings have challenged the classical temporal boundaries of irreversibility [40], even if at present the possible positive effects of clinical interventions are not evidence-based nor generally accepted by medical community [41].

It is possible that patients with DOCs preserve some neural activities related not only to wakefulness but somehow to awareness as well, although in very low degree and disconnected ways. This is particularly rel-evant for the question of misdiagnosis which is mainly caused by the difficulty to behaviorally assess consciousness (empirical limit). Moreover the possibility to retain in some way awareness in patients with DOCs is also related to a conceptual problem in establishing “lack of awareness” (theoretical limit): absence of evidence of awareness (of awareness) is taken as evidence of absence (of awareness) [14,42,43].

For the above reasons the ETFDC has proposed to change the label VS in UWS. This name refers to patients that show a number of clinical signs (hence the use of syndrome) of unresponsive ness (meaning they fail to show non-reflex behavior or command follow-ing) in the presence of wakefulness (meaning they open their eyes spontaneously or upon stimulation) [1]. Other names were rejected: coma vigil was considered a contradiction in terms, while a-pallactic syndrome was considered not appropriate, given that such patients retain some (merely primary) cortical activities [45,46].

The definition by the ETFDC, starting from new neuroscientific findings, focuses on the behavioral assessment of consciousness, underlying both what is lack (Unresponsive) and what is present (Wakefulness). The main concern of this changing is to give the possibility to be acknowledged to patients recovering from coma as having even minimal signs of consciousness. Rec-cent neuroscientific developments, in fact, show that such patients, even if unable to recover any voluntary responsiveness, may retain or recover other signs of types of consciousness [47]. The aim of the ETFDC is to give a neutral tool to physicians in order to describe the clinical condition of patients with DOCs as objec-tively as possible.

Starting from the theoretical progresses related to neuroscientific investigation, the main interest of the UWS definition is a practi-cal one: improve the management and the standard of care of patients in such a state. The premise is that if we cannot change the negative connotation of the term VS it is better to replace it.

Besides the importance to increase the collaboration between clinical practice and neuroscience, the ETFDC also stresses the need to develop new, more ef-ficacious behavioral scales to assess consciousness and the importance to identify objective para-clinical signs confirming the clinical detection of consciousness. What is happening is that the broad definition of VS/ UWS as wakefulness without awareness is increasing-under question because of the new neuroscientific findings. Particularly a consistent lack of metabolic activity in the widespread network of polymodal as-sociative cortices (located in the frontal and parietal lobes of the brain) that are involved in the cognitive processing of sensory information was identified in VS/UWS through neu-
In the aforementioned case another potential use of neuroimaging can be observed. Functional neuroimaging can be used to rule out a diagnosis of vegetative state and may even yield information about prognosis. Indeed, limited data on prognosis show that quantitave measurements of brain activity—in particular, activations beyond primary sensory cortices—are positively correlated with recovery from the vegetative state [14]. Furthermore clinical observation may be supported also by electroencephalography (EEG) [61]. These neuroscientific technologies are increasingly used to investigate patients with DOCs at rest. Particular is the so-called “default mode network”, a set of areas (posterior cingulated/ precuneus, anterior cingulated/mesio-frontal cortex, temporoparietal junctions) which are more active in at rest than during attention-demanding tasks. This default mode network is considered to be involved in self-related processes [58]. Regarding DOCs, it is rel-evant that resting state connectivity was shown to dis-appear in brain death […] and to show a non-linear disintegration in pseudomia or locked-in syndrome as compared to minimally conscious or relative to un-conscious states (VS/UWS or coma).

To assess the consciousness of patients with DOCs through fMRI of resting state may allow us to over-come the conceptual limit of a fMRI approach to consciousness: given the lack of a full understanding of the neural correlates of consciousness, even a near-to-normal activation in response to passive stimulation cannot be taken as proof of preserved awareness, but only as the manifestation of the activation of a par-ticular brain region able to activate and process sensory stimulation. Furthermore, the non activation during passive fMRI paradigms may be consequent to peripheral sensory systems’ impairments (e.g., deafness). On the contrary Resting-state fMRI acquisitions are easy to perform (i.e., do not need auditory, visual or soma-tosensory stimulation equipment in the fMRI environ-ment) and could have a potentially broader and faster translation into clinical practice [62].

Generally speaking the problem with the electrophysi-ological and neuroimaging assessment of consciousness is that the mental imagery tasks used or MRI de-tection of consciousness require high-order cognitive abilities and can be very demanding for many brain-injured patients. On the contrary event-related EEG potentials elicited by simpler sensory stimulations in-volve lower cognitive resources [47].
Starting from the assumption that consciousness is effective connectivity of the thalamocortical area, it is possible to test its presence through transcranial magnetic stimulation (TMS) and to read the relative EEG results.

**Nosography of Docs as an Ethical Problem**

To develop an appropriated nosography of DOCs, particularly of VS/UWS, is not only a scientific, but also an ethical issue, as clearly shown by three institu-tional Australian documents which preceded the scien-tific definition by ETFDC.

The definition of “Post Coma Unrespon-siveness” (PCU) has been proposed in three documents by the Australian Government, National Health and Medical Research Council: Diagnostic Framework concerning Post-coma unrespon-siveness or Vegetative state (2003), Ethical Guidelines for the Care of People in Post-Coma Unrespon-siveness (Vegetative State) or a Minimally Responsive State (2008), Post-Coma Unresponsiveness and Minimally Responsive State. A guide for families and carers of people with profound brain damage (Guide for families) (2008). In these documents PCU is suggested at the same time as a synonymous and an alternative to the commonly used VS.

The Diagnostic Framework (2004) describes PCU as follows: Post-coma unresponsiveness (VS) encompasses clinical states that follow emergence from coma in which there is apparently complete lack of purposeful responsiveness, with preservation of sleep-wake cycles and cardio-respiratory function, and partial or complete preservation of hypothalamic and brain-stem autonomic (vegetative) functions. Post-coma unresponsiveness (VS) is a manifestation of severe brain damage [63]. Although this label has the advantage to avoid the use of a temporal criterion, like persistent or permanent, its meaning seems to be too much large and it may produce a confusion between vegetative state and cerebral death.

In the document of 2003 it was also written that there are three main reasons to prefer PCU to VS: It use-fully excludes unre sponsive state (VS/UWS) that do not follow a period of coma, such as the terminal stages of Alzheimer’s disease, or the unresponsiveness seen in delop-mental abnormalities such as anencephaly; it avoids the potentially pejorative term vegetative; and it has no time-based qualifiers—that is, it could apply as soon as emergence from coma occurs and for as long as the patient remains unresponsive [63].

In the same document the essential features of PCU are described as follows:

- **long periods of wakefulness without responsive-ness.**
- **roving eyes, sometimes briefly tracking a moving object.**
- **spastic limbs, with withdrawal in response to pain, and often grasp or grope reflex in the hands.**
- **no words uttered or mouthed, no commands obeyed.**
- **no purposeful emotional responses — frowning, crying, tears, smile-like movements and laughter may occur but are divorced from appropriate stim-ul-i.**

The Ethical Guidelines of Australian Government develop a vocabulary of several disorders of consciousness and aim to promote the best interests of these vulner-able people. They define coma as a state of presumed profound unconsciousness from which the person cannot be roused when examined. Coma is not brain death; some brain function remains, and some or all may be recoverable [64].

Consequently the PCU is a state or condition in which a person has emerged from coma to the extent that he or she is observed to have sleep/wake cycles over a period of time but no purposeful responses to stimuli. Responsiveness may gradually return in some people, leading to MRS (Minimally Responsive State) or even better, although improvement may be very slow. Some recovery may be achievable but full recovery is highly improbable [64]. Interestingly the Ethical Guidelines of 2008 prefers the words “person” rather than patient.

The Australian institutional documents use the term “Minimally responsive state (MRS)” rather than “mini-mally conscious state”. This condition may arise when a person has emerged from coma or PCU. There is a minimal level of purposeful response, with discernible but inconsistent evidence of consciousness. Cognitive-ly mediated behavior occurs often enough or for long enough to distinguish it from reflex behavior, and the more complex the response, the easier it is to make this distinction [64].

The Diagnostic Framework concerning Post-coma unrespon-siveness or Vegetative state [63] underlines that PCU must be diagnosed primarily through clinical examination. The National Health and Medical Research Council recognizes the value of imaging technologies in diagnostic process but at the same time outlines their limitation: structural, functional and electrophysiological tests could establish the site and extent of brain injury, but no “gold standard test” is available.

The Ethical Guidelines [64] of Australian Government consider more carefully neuroscientific studies with neuroimaging technology [37,65]. If the Diagnostic Framework [63] recognized that there are many difficult in diagnosing PCU and distinguishing it from MRS, the Ethical Guidelines [64] specifies that it is difficult to be certain that a person who has sleep/wake cycles is not responding at all, and it is not possible to be certain that the person is unaware, or what level of awareness he or she might experience. In MRS, there may be a delay between a stimulus (e.g., touch, light, movement, a voice) and any response, and responses may be ambiguous and difficult to identify.

About diagnosis and progno-sis, the Ethical Guidelines specify that accurate diagnosis of PCU and MRS of ten takes many weeks or longer. Confront diagnosis needs to be distinguished from the provisional findings of a single clinical examination — when, for example, a person emerging from coma may be observed to be in PCU or MRS. Similarly, the prognosis for a person with a diagnosis of PCU or MRS becomes clearer only over many weeks or months [64]. From a clinical and ethical points of view, the Austra-lan Ethical Guidelines underlines that the research evidence is very limited and difficult to interpret. Furthermore, it is essential the periodic clinical reassessment in the long term, in relationship to the gradual and slow change of clinical condition. According to this document, the chances of improvement decreases with the increase of timelessness. This evaluation has only a probabilistic and not abso-lute value, because life expectancy is difficult to predict. Finally, according to the Australian Document of 2008, the general and specialist medical care are to be assured to people in PCU or MRS, including antibiotics and palliative care.

The abovementioned Australian documents shows at the same
time the importance to include neuroscientific findings in the ethical assessment of DOCs and to clear the limitation of the instrumental assessment of consciousness. Relevant ethical, social and legal issues arise from the potential inclusion of neurotechnology in the clinical examination and treatment: for instance, the allocation of economic resources, related to the fact that neuroimaging is not available in all places and in all circumstances; the competence of the medical staff who has to interpret the data; the time factor, that is the need to repeat the assessment of consciousness in different time and in different conditions; the balance between the instrumental and the behavioral assessment of consciousness.

As recently outlined by Laureys and Schiffer [66] neuro-scientists and clinicians have to face an emerging need for motor-independent signs of awareness derived directly from brain signals. Yet a clinical and ethical problem derive from the fact that in absence of motor responsiveness functional neuroimaging in principle is a more direct and objective tool to measure residual cognition in severely brain-damaged patients, while in practice the application of functional neuroimaging to patients with DOCs is often difficult and ambiguous with respect to resolving diagnostic uncertainty. This difficulty and this ambiguity, from which a diagnostic and therapeutic uncertainty arises, have important ethico-legal implications, regarding for instance the rightness of the diagnosis and the allocation of resources to implement the diagnosis. The fundamental point to take into account is that to date the uncertainty of the behavioral assessment of consciousness in patients with DOCs is not eliminated by instrumental assessment but often replaced by another form of uncertainty. For instance it is important to note that a negative result in an instrumental assessment of consciousness cannot be assumed as a proof of the absence of consciousness, while, on the other hand, positive results are informative and assumable as proof of consciousness. The interpretation of positive and negative result is part of the general problem of translating the instrumental findings “from the bench to the bedside”, and for this translation well defined ethical frameworks are necessary [66].

Furthermore a relevant clinical issue emerges, that is assessing the potential prognostic value of the neuro-imaging technique. Important ethical issues are related to this point. First of all the shifting models of recov-ery, diagnosis and prognosis which are consequence of the new discoveries could require a reframe of the ethical models as well [67,68]. For this reason it is necessary that policies for patients with disorders of consciousness keep up with the times, that is with the neuroscientific discoveries and related applications.

Further ethical and social issues arise from the increas-ing requests for new diagnostic tools by the family of patients with DOCs [69]. Particularly, relevant ethical issues emerge from the risk of unrealistic expectations by family and surrogate decisionmakers.

Ethically relevant are also the possible shortcomings and misunderstandings about the use and the value of neuroimaging: Jox et al. outline that the neuroimaging techniques are rarely or poorly explained, and the ca-pabilities of neuroimaging are often misunderstood in media coverage, in the sense that they are assumed as real picture of the brain conferring a high authority to scientific explanations in the eyes of the public.

The abovementioned concerns confirm at the same time the necessity to start from neurotechnology for a new nosography of DOCs and to clearly outline its intrinsic limitation.

Conclusion

The relevant progresses in the neuroscientific un-derstanding of consciousness and related disorders suggest a new nosography focused on a behavioral approach supported by neurotechnology. As exem-plified by the analyzed Australian documents, current guidelines should include the new neurotechnologies as a source of information for more appropriated diagnosis and prognosis of DOCs, but they should also outline the limitation of the clinical feasibility of such technologies. Relevant ethical, social and legal issues arise from the potential inclusion of instrumental assessment of consciousness in the clinical examination and treatment.

A relevant issue emerging from contemporary neurotechnology applied to DOCs is the feasibility of an appropriated nosography. Particularly, given the ex-traordinary complexity of the neural correlates of con-sciousness, the relation between them and the linguist-tic categories we use in their description raises several issues as regards to our knowledge and its impact on our practice: how much arbitrary is the nosography we use? Is it really able to express both the knowledge and the uncertainty of contemporary neuroscience?

These and other related issues deserves more attention in order to define a more appropriated interaction be-tween medicine and neurotechnology.

Authors Contribution

The authors contributed equally to the manuscript

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