Reforming the Taxonomy in Disorders of Consciousness

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This article examines the serious shortcomings that characterize the current taxonomy of postcomatose disorders of consciousness (DoC), and it provides guidelines for how an improved DoC taxonomy might be developed. In particular, it is argued that behavioral criteria for the application of DoC categories should be supplemented with brain-based criteria (eg, information derived from electroencephalography and functional magnetic resonance imaging), and that the categorical framework that currently characterizes DoC should be replaced by a multidimensional framework that better captures the performance of patients across a range of cognitive and behavioural tasks.

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In his essay "The Analytical Language of John Wilkins," Jorge Luis Borges divides all animals into 14 categories, including "Those that belong to the emperor," "Embalmed ones"; "Those that are trained," "Stray dogs", "Those that are included in this classification," "Those drawn with a very fine camel hair brush," "Those that have just broken the flower vase," and "Those that, at a distance, resemble flies." Borges's parody reminds us that taxonomy matters. A good taxonomy classifies objects on the basis of their underlying nature and in ways that are relevant to our interests and concerns.[1] Taxonomic systems can be faulted insofar as they fail to meet these requirements. Here, we make the case for thinking that the current disorders of consciousness (DoC) taxonomy is seriously deficient and should be significantly reformed if not altogether replaced.

The foundations of the current DoC taxonomy were laid over four decades ago, when Jennett and Plum[2] introduced the vegetative state (VS) as a distinct postcomatose state. Subsequent developments included the introduction of the minimally conscious state (MCS) and the emerged from minimally conscious state (EMCS).[3] Recently, two subspecies of MCS states, MCS^{+} and MCS^{-}, have been introduced (Bruno 2011).[4] Despite the heterogeneity in cognitive, behavioral, and neural profiles that is exhibited by patients, the taxonomy of DoC demands that all patients must be accommodated by one of only four central categories, only one of which includes subcategories.

Although this taxonomic system is well established, a willingness to critically evaluate its taxonomy is an indicator of scientific maturity. Indeed, even well-established fields are not immune from taxonomic upheaval. For 130 years, dinosaurs have been divided into two distinct clades, Ornithischia and Saurishia. A recent study[5] has challenged that consensus, arguing that the morphological relations between dinosaurs is better accounted for by treating Ornithischia as a sister group of a new category, Theropoda, which are united in the new clade Ornithoscelida. This proposed taxonomic revision involves the introduction of new categories, the redefinition of old categories, and a reorganization of the relationships between categories. Moreover, the authors of this study point out that the proposed revisions would not be cosmetic, but would have an impact on debates about such issues as dinosaur diet, locomotion, and point of origin.

In a similar vein, we believe that the time is ripe for a critical evaluation of the taxonomy used in the DoC field. The current taxonomy was devised before the development of techniques, such as those that involve functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), for identifying neural activity

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and responsiveness, and the data that these techniques have delivered are not easily accommodated within it. We believe that the interests of both patients and research would be best served by the development of a new taxonomy that does justice to patients' underlying conscious capacities, irrespective of whether these capacities are behaviorally manifest. This article not only shows that such revision is necessary, but it also provides some guidelines as to how such a revised taxonomy might be developed.

Problems With the Current DoC Taxonomy

The fundamental rationale for the current DoC taxonomy is to capture distinctions in a patient's capacities for conscious experience. Both the coma state (CS) and the VS are regarded as states in which the patient has no capacity for consciousness; the VS differs from the CS only with respect to the presence of wakefulness. By contrast, both the MCS and the EMCS are defined as states in which the capacity for consciousness is present. The distinction between the MCS and the EMCS—and indeed between the MCS^{-} and the MCS^{+}—concerns the kinds of conscious contents and capacities that are thought to be available to the patient. MCS patients are presumed to have the capacity for only a restricted range of rudimentary conscious contents, whereas EMCS patients are thought to be able to enjoy a much wider range of conscious contents involving greater degrees of cognitive sophistication.

In addition to capturing facts about a patient's current capacity for conscious experience, DoC categories also contain implicit information about a patient's prognosis. Knowing which of these states a patient is currently in tells us something about their chances for recovering the capacity for functional communication, for an MCS patient has a greater chance of transitioning into the EMCS than a VS patient does, and a VS patient in turn has a greater chance of transitioning into the MCS than a CS patient does. However, it should also be noted that much of the prognostic information we have regarding patients is not reflected in the DoC categories themselves. We know that VS patients who have experienced a traumatic brain injury (TBI) have a greater chance of transitioning into the MCS than those who are VS for other reasons (eg, hypoxia), but the current DoC taxonomy does not distinguish between VS patients on the basis of etiology, and both TBI and non-TBI patients are typically described in research reports simply as 'VS'.

The central puzzle raised by the current DoC taxonomy is this: *If the rationale underlying the DoC taxonomy is to capture differences in consciousness, why then are the criteria for these categories purely behavioural*? The standard assessment schedule for diagnosing the VS is the JFK Coma Recovery Scale–Revised. This scale is purely behavioral in scope, addressing only a patient's ability and/or willingness to engage in such behaviors as visual fixation and pursuit, the localization of noxious stimuli, and overt command-following. The exclusive reliance on behavior would be justified if consciousness was a behavioral phenomenon, but it is not. Behavioral capacities are, of course, one manifestation of consciousness, but they are not the only manifestation, and a decade of research has provided overwhelming evidence that consciousness can occur in DoC patients—sometimes in surprisingly sophisticated forms—in the complete absence of the capacity for intentional behavior.

The first paradigm to be developed for identifying consciousness in the absence of any behavioral response was the covert command-following paradigm.[6] While lying in the scanner, the patient is instructed to imagine one of two activities—playing tennis or visiting the rooms of his or her home—for discrete and repeated 30-second intervals. A significant minority of behaviorally nonresponsive patients show region-specific brain activity that is indistinguishable from that observed in healthy volunteers: The instruction to imagine playing tennis causes activation in the supplementary motor area, and the instruction to imagine walking around the rooms of one's house causes activation in the parahippocampal gyrus, posterior parietal lobe, and the lateral premotor cortex.[6–8] Importantly, this activation is time-locked to the command. Command-following studies have been conducted with both fMRI[6,9,10] and EEG.[11,12] A recent meta-analysis suggests that approximately 15% of study participants who satisfy the behavioral diagnosis of VS possess some capacity to respond to commands.[13]

The command-following paradigm has not only provided evidence of consciousness in its own right, it has also enabled us to discover independent evidence of consciousness in certain DoC patients in the form of higher-level cognition. The most striking studies have used command-following as a channel of communication. The first of these studies was conducted by Monti et al,[8] who asked a VS patient six yes/no autobiographical questions (such as, "Is your father's name Alexander?"). The patient, who had been instructed to engage in either motor imagery or spatial imagery (depending on the trial) in order to answer "yes" or "no", produced activation indicative of a correct answer in response to five of the six questions. (The sixth question elicited no significant activation in the regions of interest.)

Other paradigms have been developed for identifying modes of higher cognition in nonresponsive patients. Naci et al[14] presented healthy volunteers and 2 VS patients with an engaging, 8-minute Alfred Hitchcock film entitled, "Bang! You're Dead" while recording their brain activity with fMRI. The film's plot involves a young boy who has mistaken his uncle's loaded revolver for a toy. At several points throughout the film, the boy spins the cylinder—as in a game of Russian roulette—and, taking aim at other characters, pulls the trigger. Naci et al[14] found that brain regions associated with executive processing (such as the frontoparietal network) were synchronized across healthy participants while viewing the film. This was contrasted with the absence of synchronization in data derived from resting-state trials and trials involving a scrambled version of the film, suggesting that the neural synchronization was driven by the film's plot. This synchronization model was then compared against the brain activity of 2 VS patients as they viewed the film. One of these 2 patients—an individual who had been repeatedly diagnosed as vegetative for 16 years—produced brain activity that was highly synchronized with that of healthy participants, suggesting that while viewing the film his experiences mirrored those of the healthy participants (see also Naci et al[15]).

In sum, there is now overwhelming evidence that significant numbers of VS patients—that is, patients who are *correctly* diagnosed as VS according to current clinical guidelines—are conscious. Indeed, in some cases, their conscious capacities rival not just those of MCS, but also those of EMCS patients. Even more profound disruption to the current DoC taxonomy is suggested by evidence of covert consciousness in some comatose patients.[16] There is thus a fundamental tension between the diagnostic criteria that are currently used in categorizing DoC patients and the rationale that undergirds DoC taxonomy. How should we respond to this tension?

How Not to Reform the Taxonomy of DoC

Some researchers have suggested that covertly conscious nonresponsive patients should not be grouped with either VS patients or with MCS patients, but should be assigned their own category.[4,17–19] One authority has suggested that this category be labeled "cognitive motor dissociation."[20]

We do not find this proposal compelling. Although we certainly agree that is important to indicate that a patient has cognitive abilities that are not behaviorally evident, we do not think it wise to introduce a novel category that would apply only to such patients. The introduction of such a category would imply that the distinction between patients whose conscious experiences are manifest in their overt behavior and patients whose conscious experience are not overtly manifest is a fundamental one. In our view that implication is mistaken. Although this distinction might be relevant for certain purposes, there are strong ethical and scientific reasons for distinguishing between patients solely on the basis of their conscious states and capacities. The fact that our method for identifying a patient's conscious states and capacities is overt (ie, based on their behavior) or covert (eg, based on their neural responses) should not be reflected in the basic DoC categories to which the patient is assigned.

Another response to the tension we have identified would be to retain the conceptual structure and diagnostic criteria of the current DoC taxonomy, but reconceptualize the rationale that underlies it. Thus, rather than take this taxonomy to be in the business of distinguishing between DoC patients on the basis of their capacities for subjective experience, we might instead think of this taxonomy as tracking distinctions in the behavioral capacities of patients. (Of course, if we were to adopt this approach, then it would need to be accompanied by the relabeling of these categories to avoid terms associated with consciousness.)

We are not inclined to endorse this response either. In our view, DoC taxonomy ought to capture distinctions between the capacities for consciousness that patients have, for it is these distinctions that are of primary importance when it comes to the welfare of patients.[21] Rather than revise the rationale that underlies DoC taxonomy so that it comports with our current categories and criteria, we should reform the criteria and, if necessary, the very categories themselves so that they reflect our interests in classifying patients. The following two sections consider how such reforms might be implemented.

Modest Reform

A relatively conservative way to reform the DoC taxonomy would be to retain the current suite of DoC categories (eg, CS, VS, MCS, and EMCS) and revise only the diagnostic criteria that are used for assigning patients to a particular category. For example, one might allow a patient to be diagnosed as MCS on the basis of his or her performance on any one of the neurally based tasks surveyed above. One can also imagine revisions to the behavioral criteria associated with the current DoC categories as our understanding of the relationship between consciousness and behavior improves.

Although a number of theorists have called for neurally based tasks to be incorporated into DoC assessment schedules,[13,22–25] such calls have yet to be heeded, and the official criteria associated with DoC categories remain purely behavioral. The rejection of neural measures appears to be primarily motivated by worries about their evidential status. According to the authors of a recent review of assessment scales used in DoC, neural measures "do not have

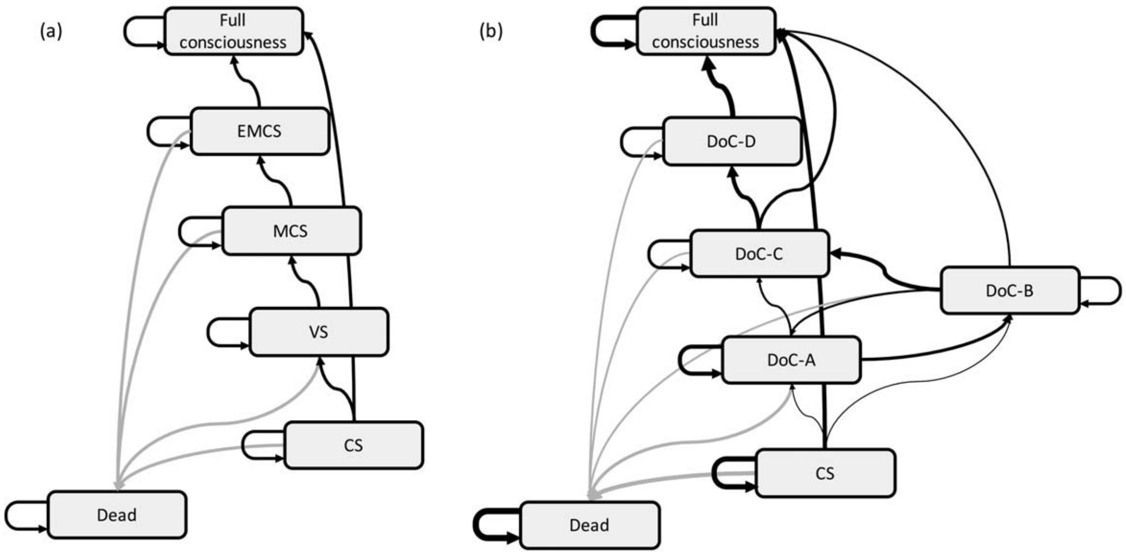

FIGURE 1: Potential structure of a dynamic DoC taxonomy. (A) Traditional taxonomy illustrated as a Markov chain; DoCs are represented as discrete states with probabilities for staying in that state and for transition to other states. (B) Potential dynamic taxonomy with a set of potentially new categories of DoC (DoC-A-D) added, changing the causal structure of the taxonomy (thickness of arrows represents dummy values for transition probabilities). CS = coma state; DoC = disorders of consciousness; EMCS = emerged from minimally conscious state; MCS = minimally conscious state; VS = vegetative state.

sufficient evidentiary support to be included in formal diagnostic criteria or routine clinical care."[26,27]

It is certainly true that questions can be raised about the evidential status of covert measures of consciousness, but the force of such worries should not be exaggerated. Four points should be noted. First, the evidential force of some covert measures of consciousness can be justified by appealing to the fact that they are direct analogues of currently accepted behavioral measures, and thus they inherit the evidential force of those behavioral measures.[28] The most prominent instance of such a measure is the command-following paradigm. Covert command-following should be regarded as diagnostic of consciousness given that overt command-following is so regarded, for the evidential value of overt command-following with respect to questions of consciousness clearly has nothing to do with the fact that it is overt.

Second, we can determine the evidential force of other covert measures by considering their fit (or consilience) with other putative markers of consciousness[28,29] and their integration with our best theories of consciousness. Our capacity to validate putative markers of consciousness in this manner is limited by the fact that the science of consciousness remains in a relatively immature state, but as our understanding of the neural basis of consciousness improves, so, too, will our capacity to validate putative covert markers of consciousness.

Third, we should treat "negative" results on covert measures of consciousness in much the same way that we treat "negative" results on overt measures of consciousness. Negative findings are not epistemically worthless (for an absence of evidence can, sometimes, be evidence of absence), but given the difficulties in distinguishing false negatives from true negatives, they should be treated with caution just as the failure of a patient to produce a certain kind of motor response should be.

Finally, it should be noted that questions about validation are by no means restricted to "covert" measures of consciousness, but can also be raised with respect to the behaviors that are currently used to ascribe consciousness to DoC patients. For example, consider the role that the CRS-R assigns to the capacity for visual fixation and tracking. Although it is intuitively plausible to treat these behaviors as markers of consciousness, given the fact that many eye movements are controlled unconsciously,[30] it would not be unreasonable to ask whether we have "sufficient evidentiary support" for treating visual fixation and tracking as indicators of consciousness. As our understanding of the relationship between the control of eye movements and consciousness improves, so, too, will our ability to determine how eye movements ought to be incorporated into DoC assessment schedules.

Radical Reform

A more radical revision to DoC would involve revising not just the diagnostic criteria associated with DoC categories, but overhauling the very categories themselves. Instead of operating with a relatively austere structure involving only four, discrete, categories, it is possible to envisage a number of alternative taxonomic structures, each of which would enable us to better capture the full

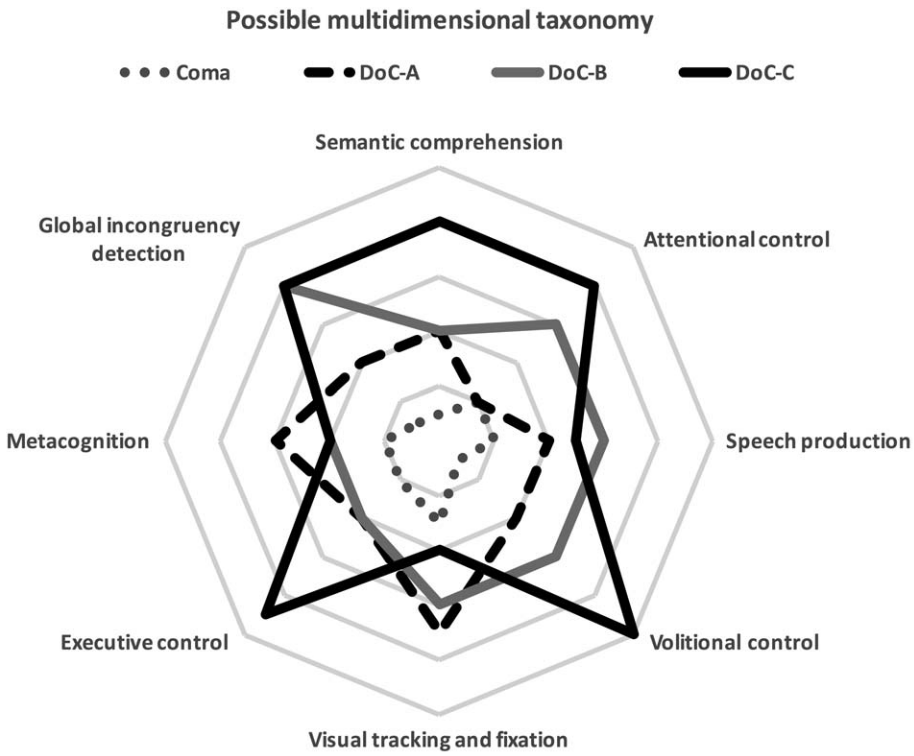

FIGURE 2: The multidimensional structure of consciousness, with eight dimensions chosen here for illustrative purposes only (based on Bayne et al 2016[31] and Sergent et al 2017[32]. DoC = disorders of consciousness).

spectrum of consciousness-related capacities exhibited by DoC patients.[31,32]

One way in which to reform the categorical structure of this domain would be to retain the current ordinate categories of VS, MCS, and EMCS, but introduce additional subordinate categories on the model of MCS^+ and the MCS^-.[4] For example, one might distinguish between $EMCS^-$ patients and $EMCS^+$ patients, where the $EMCS^-$ category would apply to patients who possess the capacity for certain forms of high-level cognition, such as those that are recruited by the Hitchcock study,[14] but lack the capacity for functional communication, and the $EMCS^+$ category would apply to patients who possess all of the capacities had by $EMCS^-$ patients, but also have the capacity for functional communication.

A second way in which to reform the categorical structure of this domain would be to replace some (or even all) of the categories of VS, MCS, and EMCS with categories that may not be related to one another in the ways in which these categories are. For example, one might introduce the categories of DOC-A, … DOC-D, where there is no assumption that these categories stand in a strict hierarchical relationship to one another in the way that the current DoC categories do. Instead, these labels might simply identify groups of patients that exhibit distinct clusters of consciousness-related capacities. Identifying these categories would require the use of methods of cluster analysis (aka "taxonomy analysis"), which would group together patients that display similar characteristics, irrespective of whether those characteristics are behavioral, cognitive, or neural. For example, DOC-A patients might turn out to exhibit a wide variety of sensory and affective forms of experience, but exhibit poor executive control, whereas DOC-B patients might possess robust forms of executive control, but exhibit little in the way of sensory or affective experience. An informative way of depicting the resulting categories and their relations is by a Markov chain (see Fig 1).

A third way to reform the categorical structure of this domain would be to replace the current categories, which are discrete, with categories that are graded and represent regions in a multidimensional space. Although some MCS patients clearly have a broader array of cognitive, perceptual, and affective capacities than others, the logic of the current taxonomy means that one patient cannot be described as "more MCS" than another, and MCS patients that are near the VS/MCS border cannot be distinguished from MCS patients that are near the MCS/EMCS border. This is unfortunate, for it results in a loss of information that is relevant to both clinical patient care and scientific research. Moving to a multidimensional taxonomy would enable this information to be retained and communicated, for conceiving of DoC categories as corresponding to regions in a multidimensional space would enable us to represent patient 1 as more DOC-A than patient 2 on the grounds that patient 1 is nearer the centre of the DOC-A region than patient 2 is (Fig 2).

Moreover, because the envisaged framework would be *multi*dimensional, it would enable us to represent the fact that although patient 1 does better on one dimension of cognitive/behavioral control than patient 2, patient 2 does better on another dimension of cognitive/behavioral control than patient 1.[32] Such facts cannot be represented within a discretely structured taxonomy, even with the introduction of novel categories.

Whether or not the novel categories that might be included in a future DoC taxonomy are discrete states or regions in a multidimensional space, there are questions about how they might be identified. What tools should we use for constructing a new set of DoC categories?

Perhaps we can learn from the dinosaurs. Baron et al[5] arrived at a novel set of categories for dinosaur taxonomy by modeling the relationships between 457 characteristics of dinosaur anatomy, and then identifying groups that accounted for points of convergence and divergence between these characteristics (groups that could not be accommodated within the existing taxonomy). In a similar spirit, we suggest that we ought to develop a new DoC taxonomy by modeling the relationships between the various behavioral, cognitive, and neural capacities of patients. The resulting taxonomy will thus better reflect the multifaceted ways in which consciousness is retained in this complex and vulnerable population. There are, of course, challenges in ensuring that this taxonomy has clinical utility, but there is every reason to believe that such challenges can be met.

Author Contributions

All authors contributed equally to the writing of the manuscript.

Potential Conflicts of Interest

Nothing to report.

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