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CONSCIOUSNESS AND THE VEGETATIVE STATE: TODAY
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INTRODUCTION

CONSCIOUSNESS: TODAY

"*To demonstrate existential characters of neurons, any theoretically conceivable net embodying the possibility will serve.*" (Pitts, McCulloch, 1948)

Consciousness is a multifaceted concept combining awareness and wakefulness. In everyday neurology it is usually equated to the waking state, and fluctuations in the level of vigilance are thought to reflect changes in brain (cortical) activation. It is believed to imply (subjective) experience and awareness of self (self-consciousness, self-detection, awareness of awareness, self-knowledge) and of environment (1). Jackson (2) restricted consciousness to the momentary relationship between the subject and the object or (in his anatomical-physiological terms) to the organism adjustment to the environment. However, perception and behaviour are possible without formal awareness (3–8) and some sustained (self)consciousness also exists during sleep, as we remain ourselves in the most unrealistic dreams and are also aware of our dreaming (9).

Today, research on consciousness is expanding, with a major focus on its understanding in relation to cortical/brain activation or functional complexity, long-range connectivity, neuronal synchronization in selected frequency ranges, uni/multimodal perception, motor activation, focused attention, etc. The major current theories about consciousness involve large-scale information processing, social processes, or neurobiological mechanisms (1). Distinctions between consciousness and attention have been documented (10–12), with implication in the cognitive neuroscience that consciousness could be distinct from other higher brain functions (13). The brain structures and processes thought to mediate in sustaining consciousness nevertheless are identified by the impairment of varying severity that results from local damage. Consciousness thus appears to be the result of a complex functional arrangement in which sustained sensory input, activation of non-specific ascending systems and primitive motor systems, activation of cortical neurones at due frequency, sensory-motor interaction, and balanced metabolism and neurotransmitters modulation are crucial (14, 15). This complex functional set-up conceivably also accounts for some specificity of the neurological signs predicting the outcome from the vegetative state (also referred to as unresponsive wakefulness syndrome) (16) and its evolution into a minimally conscious state (17–23).

Further investigation is needed to define the extent to which the reported electrophysiological, functional magnetic resonance imaging, positron emission tomography scan or autonomic changes imply some specificity of response or have clinical or prognostic relevance. This caveat notwithstanding, neuroimaging has documented retained connectivity in segregated networks in response to stimulus conditions in both minimally conscious and vegetative state subjects, with indication of the capability of the severely damaged brain to express surviving modular functions in the absence of the integrative processes necessary to consciousness (24–28). Although restricted to a relatively small portion of patients (29), this evidence further promoted research on the neuronal correlates of (un)consciousness (30) and expanded the clinical scenario. As a result, the vegetative and minimally conscious states appear today neither static nor homogeneous, and a tacit revision of the anatomo-functional set-ups underlying these conditions is *de facto* underway, warranting a formal nosographic revision of the current descriptive categories or accuracy of diagnosis (16, 31).

Regionally-mediated micro-consciousness processes have been proposed based on evidence of local neuronal organization in visual perception (32). On the other hand, increased synchronization between large neuronal populations of distinct areas related to perceptual dominance has been documented during conscious visual perception (33). The observation is consistent with evidence suggesting that neuronal activity synchronizes across cortical areas at conscious perception and with the theories of neural integration and complexity accounting for the properties of conscious experience and consciousness itself (13, 34–37). Long-range synchronization (e.g. in the gamma range) is thought to mediate in conscious perception (33) as it does in binding visual features and in all conditions in which neurones are selectively assembled to respond to any momentary functional requirement (38–44). However, its role in sustaining consciousness remains undocumented (45). In this respect, the major unsolved problem of biology is how billions of nerve cells work together to create consciousness (46, 47).

Consciousness is topical and is increasingly attracting scientists in neuroscience, medicine, neurocomputing, artificial intelligence, and robotics. Interest is increasing with the rapid progress in the investigation of higher brain function, advances in artificial intelligence, and diffuse perception of the inadequacy of traditional mind/body separations. The issue is also crucial in methodological and bioethical controversies pertaining to medicine and public or private healthcare (16, 31, 48). However, consciousness and related terms remain to a significant extent ambiguously defined and inadequately characterized. Peculiar conditions, such as epilepsy or the vegetative and minimally conscious states, may question the correlation between wakefulness and awareness and the available computational models of brain activity (30, 49, 50). Research attempting to correlate the contents of conscious experience with representations in specific neural populations relies to a relevant extent on the linguistic neutrality of "correlates" when the experimental paradigms and explanatory canons of neuroscience are not neutral about the mechanical relations with the brain and are supposed to investigate causes

(51). A taxonomy of conscious, preconscious, and subliminal processing is still needed (52).

Neuroscience has advanced to the point that it appears that we can now treat consciousness as a scientific problem like any other (53), disregarding objections that it is epiphenomenal, not evolutionary in function, unaccountable by brain processes, unsuitable to objective investigated, etc. (53). To this end, a proper definition of consciousness and an up-to-date scrutiny of its descriptors are needed in order to be able to think scientifically about consciousness and to design experimental studies.

REFERENCES

1. Zeman A. Consciousness. Brain 2001; 124: 1263–1289.
2. Jackson JH. On the scientific and empirical investigation of epilepsies. Med Pres Cir 1876; 1: 63–65, 129–131, 173–176, 313–316.
3. Weiskrantz L, Cowey A, Le Mare C. Learning from the pupil: a spatial visual channel in the absence of V1 in monkey and human. Brain 1998; 121: 1065–1072.
4. Grill-Spector K, Kourtzi Z, Kanwisher N. The lateral occipital complex and its role in object recognition. Vis Res 2001; 41: 1409–1422.
5. Marois R, Yi DJ, Chun MM. The neural fate of consciously perceived and missed events in the attentional blink. Neuron 2004; 41: 465–472.
6. Sergent C, Baillet S, Dehaene S. Timing of the brain events underlying access to consciousness during the attentional blink. Nat Neurosci 2005; 8: 1391–1400.
7. Celesia GG, editor. Disorders of visual processing. In: J Daube, F Mauguire, series editors. Handbook of clinical neurophysiology, vol 6. Elsevier: Amsterdam; 2005.
8. Radoeva PD, Prasad S, Brainard DH, Aguirre GK. Neural activity within area V1 reflects unconscious visual performance in a case of blindsight. J Cogn Neurosci 2008; 20: 1927–1939.
9. Kahn D, Gover T. Consciousness in dreams. Int Rev Neurobiol 2010; 92: 181–195.
10. Koch C, Tsuchiya N. Attention and consciousness: two distinct brain processes. Trends Cogn Sci 2008; 12: 44.
11. van Boxtel JJ, Tsuchiya N, Koch C. Opposing effects of attention and consciousness on afterimages. Proc Natl Acad Sci USA 2010; 107: 8883–8888.
12. Dienes Z, Seth AK. Measuring any conscious content versus measuring the relevant conscious content: comment on Sandberg et al. Conscious Cogn 2010; 19: 1079–1080.
13. Tononi G, Koch C. The neuronal correlates of consciousness: an update. Ann NewYork Acad Sci 2008; 1124: 239–362.
14. Dolce G, Sazbon L, editors. The posttraumatic vegetative state. Stuttgart: Thiene; 2002.
15. Dolce G, Quintieri M, Serra S, Lagani V, Pignolo L. Clinical signs and early prognosis in vegetative state: a decisional tree, data-mining study. Brain Inj 2008; 22: 617–623.
16. Laureys S, Celesia GG, Cohadon F, Lavrijsen J, León-Carrión J, Sannita WG, et al. European Task Force on Disorders of Consciousness. Unresponsive wakefulness syndrome: a new name for the vegetative state or apallic syndrome. BMC Med 2010; 8: 68.
17. Multi-Society Task Force on PVS. Statement on medical aspects of the persistent vegetative state. N Eng J Med 1994; 330: 1499–1508.
18. Giacino JT, Kalmar K. The vegetative and minimally conscious states: a comparison of clinical features and functional outcome. J Head Trauma Rehabil 1997; 12: 36–51.
19. Giacino JT, Ashwal S, Childs N, Cranford R, Jennett B, Katz DJ, et al. The minimally conscious state: definition and diagnostic criteria. Neurology 2002; 58: 349–353.
20. Giacino JT, Kalmar K, Whyte J. The JFK Coma Recovery Scale – revised: measurement characteristics and diagnostic utility. Arch Phys Med Rehabil 2004; 85: 2020–2029.
21. Jennett B. The vegetative state. Cambridge, UK: University Press; 2002.
22. Dolce G, Lucca LF, Rogano S, Candelieri A, Pignolo L, Sannita WG. Visual pursuit in the severe disorder of consciousness. J Neurotrauma 2011; 28: 1149–1154.
23. Monti MM, Laureys S, Owen AM. The vegetative state. BMJ 2010; 341: c3765.
24. Plum F, Schiff N, Ribary U, Llinás R. Coordinated expression in chronically unconscious persons. Philos Trans R Soc Lond B, Biol Sci 1998; 353: 1929–1933.
25. Schiff ND, Ribary U, Moreno DR, Beattie B, Kronberg E, Blasberg R, et al. Residual cerebral activity and behavioral fragments can remain in the persistently vegetative brain. Brain 2002; 125: 1210–1234.
26. Kotchoubey B, Lang S, Mezger G, Schmalohr D, Schneck M, Semmler A, et al. Information processing in severe disorders of consciousness: vegetative state and minimally conscious state. Clin Neurophysiol 2005; 116: 2441–2453.
27. Laureys S, Perrin F, Schnakers C, Boly M, Majerus S. Residual cognitive function in comatose, vegetative and minimally conscious states. Curr Opin Neurol 2005; 18: 726–733.
28. Riganello F, Sannita WG. Residual brain processing in vegetative state. J Psychophysiol 2009; 23: 18–26.
29. Monti MM, Vanhaudenhuyse A, Coleman MR, Boly M, Pickard JD, Tshibanda L, et al. Willful modulation of brain activity in disorders of consciousness. N Engl J Med 2010; 362: 579–589.
30. Laureys S, Piret S, Ledoux D. Quantifying consciousness. Lancet Neurol 2005; 4: 789–790.
31. Dolce G, Sannita WG, the European Task Force On The Vegetative State. The vegetative state: a syndrome seeking revision? Brain Inj 2010; 24: 1628–1629.
32. Zeki S. The disunity of consciousness. Trends Cogn Sci 2003; 7: 214–218.
33. Srinivasan R, Russell DP, Edelman GM, Tononi G. Increased synchronization in neuromagnetic responsess during conscious perception. J Neurosci 1999; 19: 5435–5438.
34. Koch C, Laurent G. Complexity and the nervous system. Science 1999; 284: 96–98.
35. Tononi G, Edelman GM. Consciousness and complexity. Science 1998; 282: 1846–1851.
36. Tononi G. Consciousness, information integration, and the brain. Progr Brain Res 2005; 150: 109–126.
37. Moreno D, Schiff ND, Giacino J, Kalmar, K, Hirsch J. A network approach to assessing cognition in disorders of consciousness. Neuroloy 2010; 75: 1871–1978.
38. Bressler SL. The gamma wave: a cortical information carrier? Trends Neurosci 1990; 13: 161–162.
39. Engel AK, König P, Kreiter AK, Schillen TB, Singer W. Temporal coding in the visual cortex: new vistas on integration in the nervous system. Trends Neurosci 1992; 15: 218–226.
40. Gray CM. The temporal correlation hypothesis of visual feature integration: still alive and well. Neuron 1999; 24: 111–125.
41. Jefferys JG, Traub RD, Whittington MA. Neuronal networks for induced '40 Hz' rhythms. Trends Neurosci 1996; 19: 202–208.
42. Singer W. Synchronization of cortical activity and its putative role in information processing and learning. Ann Rev Physiol 1993; 55: 349–374.
43. Traub RD, Jefferys JGR, Whittington MA. Fast oscillations in cortical circuits. Computational neuroscience. Cambridge, MA: MIT Press; 1999.
44. Sannita WG. Stimulus-specific oscillatory responses of the brain: a time/frequency-related coding process. Clin Neurophysiol 2000; 111: 565–583.
45. Carozzo S, Garbarino S, Serra S, Sannita WG. Function-related

gamma oscillations and conscious perception. J Psychophysiol 2010; 24: 102–106.
46. Sannita WG. Neuronal functional diversity and collective behaviors. J Biol Phys 2008; 34: 267–278.
47. Arecchi FT, Meucci R, Sannita WG, Farini A, guest editors. Neuroscience today: neuronal functional diversity and collective behaviors. Cogn Proc, Suppl 1, 2009.
48. Racine E, Amaram R, Seidle M, Karczewska M, Illes J. Media coverage of the persistent vegetative state and end-of-life decision-making. Neurology 2008; 71: 1027–1032.
49. Seth AK, Dienes Z, Cleeremans A, Overgaard M, Pessoa L. Measuring consciousness: relating behavioural and neurophysiological approaches. Trends Cogn Sci. 2008; 12: 314–321.
50. Overgaard M, Timmermans B, Sandberg K, Cleeremans A. Optimizing subjective measures of consciousness. Conscious Cogn 2010; 19: discussion 682–684.
51. Neisser J. Neural correlates of consciousness reconsidered. Conscious Cogn 2011 Apr 12 [Epub ahead of print].
52. Dehaene S, Changeux JP, Naccache L, Sackur J, Sergent C. Conscious, preconscious, and subliminal processing: a testable taxonomy. Trends Cogn Sci 2006; 10: 204–211.
53. Crick F, Koch C. Consciousness and neuroscience. Cereb Cortex 1998; 8: 97–107.
54. Searle JR. How to study consciousness scientifically. Philos Trans R Soc Lond B Biol Sci 1998; 353: 1935–1942.

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