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CHAPTER 4

Global workspace theory of consciousness: toward a cognitive neuroscience of human experience?

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Abstract: Global workspace (GW) theory emerged from the cognitive architecture tradition in cognitive science. Newell and co-workers were the first to show the utility of a GW or “blackboard” architecture in a distributed set of knowledge sources, which could cooperatively solve problems that no single constituent could solve alone. The empirical connection with conscious cognition was made by Baars (1988, 2002). GW theory generates explicit predictions for conscious aspects of perception, emotion, motivation, learning, working memory, voluntary control, and self systems in the brain. It has similarities to biological theories such as Neural Darwinism and dynamical theories of brain functioning. Functional brain imaging now shows that conscious cognition is distinctively associated with wide spread of cortical activity, notably toward frontoparietal and medial temporal regions. Unconscious comparison conditions tend to activate only local regions, such as visual projection areas. Frontoparietal hypometabolism is also implicated in unconscious states, including deep sleep, coma, vegetative states, epileptic loss of consciousness, and general anesthesia. These findings are consistent with the GW hypothesis, which is now favored by a number of scientists and philosophers.

Introduction

Shortly after 1900, behaviorists attempted to purge science of mentalistic concepts like consciousness, attention, memory, imagery, and voluntary control. “Consciousness,” wrote John B. Watson, “is nothing but the soul of theology.” But as the facts accumulated over the 20th century, all the traditional ideas of James (1890) and others were found to be necessary. They were reintroduced with more testable definitions. Memory came back in the 1960s; mental imagery in the 1970s; selective attention over the last half century; and consciousness last of all, in the last decade or so.

It is broadly true that what we are conscious of, we can report with accuracy. Conscious brain events

are therefore assessed by way of reportability. We now know of numerous brain events that are reportable and comparable ones that are not. This fact invites experimental testing: why are we conscious of *these words at this moment*, while a few seconds later they have faded, but can still be called to mind? Why is activity in visual occipitotemporal lobe neurons reportable, while visually evoked activity in parietal regions is not? Why does the thalamocortical system support conscious experiences, while the comparably large cerebellum and basal ganglia do not? How is waking consciousness impaired after brain damage? These are all testable questions. The empirical key is to treat consciousness as a controlled variable.

A growing literature now compares the brain effects of conscious and unconscious stimulation. Precise experimental comparisons allow us to ask what conscious access does “as such.” Many

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techniques are used for this purpose. In visual backward masking, a target picture is immediately followed by a scrambled image that does not block the optical input, but renders it unconscious (Dehaene et al., 2001). Binocular rivalry has been used for the same reason: it shows that when two competing optical streams enter the two eyes, only one consistent interpretation can be consciously perceived at any given moment (Leopold and Logothetis, 1999). Most recently, several studies have demonstrated inattentional blindness, in which paying attention to one visual flow (e.g., a bouncing basketball) blocks conscious access to another one at the very center of visual gaze (e.g., a man walking by in a gorilla suit) (Simons and Chabris, 1999). These studies generally show that unconscious stimuli still evoke local feature activity in sensory cortex. **But what is the use of making something conscious if even unconscious stimuli are identified by the brain?** More than a score of studies have shown that although unconscious visual words activate known word-processing regions of visual cortex, the same stimuli, when conscious, trigger widespread additional activity in frontoparietal regions (e.g., Dehaene et al., 2001).

A rich literature has arisen comparing conscious and unconscious brain events in sleep and waking, general anesthesia, epileptic states of absence, very specific damage to visual cortex, spared implicit function after brain damage, attentional control (also see Posner, this volume), visual imagery, inner speech, memory recall, and more (Crick and Koch, 2003). In state comparisons, significant progress has been made in understanding epileptic loss of consciousness (Blumenfeldt and Taylor, 2003; Blumenfeld, this volume), general anesthesia (Fiset et al., 2001; John et al., 2001; Alkire and Fiset et al., this volume) and sleep¹ (Steriade, 2001; Maquet, this volume).

¹At the level of cortical neurons, bursting rates do not change in deep sleep (Steriade, 2001). Rather, neurons pause together at <4Hz between bursts. Synchronous pausing could disrupt the cumulative high-frequency interactions needed for waking functions such as perceptual continuity, immediate memory, sentence planning, motor control, and self-monitoring. It is conceivable that other unconscious states display similar neuronal mechanisms.

The global access hypothesis

The idea that consciousness has an integrative function has a long history. Global workspace (GW) theory is a cognitive architecture with an explicit role for consciousness. Such architectures have been studied in cognitive science, and have practical applications in organizing large, parallel collections of specialized processors, broadly comparable to the brain (Newell, 1994). In recent years, GW theory has been found increasingly useful by neuroscientists. The theory suggests a *fleeting memory capacity that enables access between brain functions that are otherwise separate*. This makes sense in a brain that is viewed as a massive parallel set of specialized processors. In such a system, coordination and control may take place by way of a central information exchange, allowing some processors — such as sensory systems in the brain — to distribute information to the system as a whole. This solution works in large-scale computer architectures, which show typical “limited capacity” behavior when information flows by way of a GW. A sizeable body of evidence suggests that consciousness is the primary agent of such a global access function in humans and other mammals (Baars, 1988, 1997, 2002). The “conscious access hypothesis” therefore implies that conscious cognition provides a gateway to numerous capacities in the brain (Fig. 1). A number of testable predictions follow from this general hypothesis (Table 1).

A theater metaphor and brain hypotheses

GW theory may be thought of as a theater of mental functioning. Consciousness in this metaphor resembles a bright spot on the stage of immediate memory, directed there by a spotlight of attention under executive guidance. Only the bright spot is conscious, while the rest of the theater is dark and unconscious. This approach leads to specific neural hypotheses. For sensory consciousness the bright spot on stage is likely to require the corresponding sensory projection areas of the cortex. Sensory consciousness in different modalities may be mutually inhibitory, within

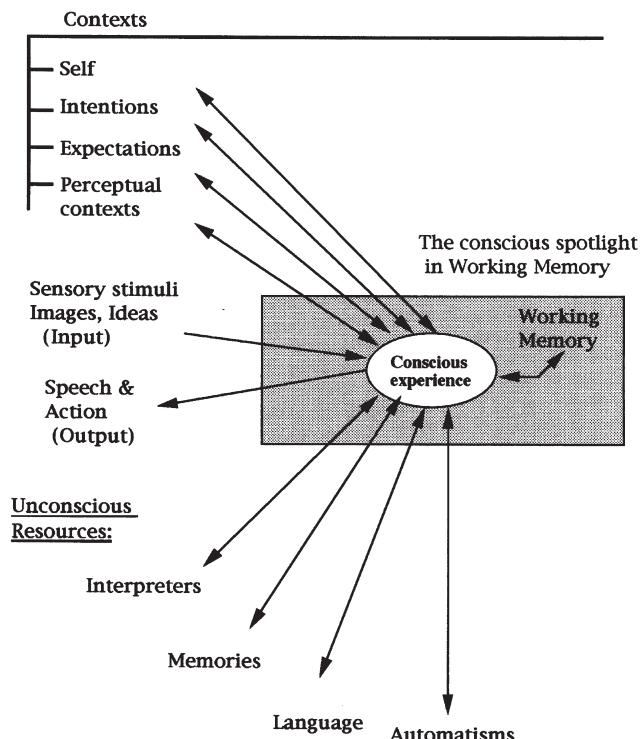


Fig. 1. A schematic diagram of GW theory, viewed metaphorically as a theater of mind. Conscious contents correspond to the bright spot on the stage of working memory. Once conscious, they activate many unconscious regions of the brain, including interpreters, memories, language capacities, and automatisms. In brain terms, those would be involved in certain cortical regions, hippocampus, and basal ganglia, which are believed not to directly support conscious experiences. However, conscious cognitions themselves are always shaped by unconscious contexts. Executive functions (self) may be considered as one set of such contexts (Adapted from Baars, 1997).

Table 1. Theoretical claims: brain capacities enabled by conscious events

1. Conscious perception enables access to widespread brain sources; unconscious sensory processing is much more limited
2. Conscious perception, inner speech, and visual imagery enable working memory functions; there is no evidence for unconscious access to working memory
3. Conscious events enable almost all kinds of learning: episodic and explicit learning, but also implicit and skill learning
4. Conscious perceptual feedback enables voluntary control over motor functions, and perhaps over any neuronal population and even single neurons
5. Conscious contents can evoke selective mechanisms (attention) and be evoked by it
6. Consciousness enables access to the “observing self” — executive interpreters, involving parietal and prefrontal cortex

approximately 100 ms time cycles (Baars and Franklin, 2003). Sensory cortex can be activated internally as well as externally, resulting in the “internal senses” of conscious inner speech and imagery. Once a conscious sensory content is established, it is distributed widely to a decentralized “audience” of expert networks sitting in the

darkened theater, presumably using corticocortical and corticothalamic fibers. The transfer of information from conscious visual episodes to the (unconscious) hippocampal system is a clear example of such distribution of conscious information in the brain (Moscovitch, 1995). This is the primary functional role of consciousness: to allow

1 a theater architecture to operate in the brain, in
 3 order to integrate, provide access, and coordinate
 5 the functioning of very large numbers of specialized networks that otherwise operate autonomously.
 7 All the elements of GW theory have reasonable brain interpretations, allowing us to generate a set of specific, testable brain hypotheses about consciousness and its many roles in the
 9 brain. Some of these ideas have now received considerable empirical support (Baars, 2002; Baars et al., 2003).

11 The theory has been implemented in computational and neural net models and bears a family resemblance to Neural Darwinist models (Edelman, 2003). Franklin and colleagues have implemented GW theory in large-scale computer agents, to test its functionality in complex practical tasks (Franklin, 2001). IDA (for “intelligent distributed agent”), the current implementation of the extended GW architecture directed by Franklin, is designed to handle a very complex artificial intelligence task normally handled by trained human beings (also see Aleksander on machine consciousness in this volume). The particular domain in this case is interaction between U.S. Navy personnel experts and sailors who move from job to job. IDA negotiates with sailors via e-mail, and is able to combine numerous regulations, sailors’ preferences, time, location and travel considerations into human-level performance.
 21 While it has components roughly corresponding to human perception, memory, and action control, the heart of the system is a GW architecture that allows the content or meanings of the messages to be widely distributed, so that specialized programs called “codelets” can respond with solutions to centrally posed problems. Franklin writes that “The fleshed out global workspace theory is yielding hopefully testable hypotheses about human cognition. The architectures and mechanisms that underlie consciousness and intelligence in humans can be expected to yield information agents that learn continuously, adapt readily to dynamic environments, and behave flexibly and intelligently when faced with novel and unexpected situations.” (<http://csrg.cs.memphis.edu/>). Similar architectures have been applied to difficult problems like speech recognition. While such auton-

1 omous agent simulations do not prove that GW
 3 architectures exist in the brain, they give an existence proof of their functionality. It is worth noting that few integrative theories of mind or
 5 brain show functional utility in applied settings.

Sensory consciousness as a test case

7 Visual consciousness has been studied in depth, and there is accepted evidence that visual features that become conscious are identified by the brain in the ventral stream of visual cortex. There, feature-sensitive cells support visual experiences of light, color, contrast, motion, retinal size, location, and object identity; small lesions can selectively abolish those conscious properties without affecting other aspects of conscious vision (Zeki, 2001; Naccache, in this volume).

9 However, to recollect the experience of a human face, we need the hippocampal system. To respond to it emotionally, neurons in amygdala may be activated. But hippocampus and amygdala do not seem to support conscious contents directly (Moscovitch, 2001). Thus, the ventral visual stream, which is needed for specific conscious contents, seems to influence regions that are not.

11 Dehaene and colleagues have shown that backward-masked visual words evoked brain activity confined to the well-known visual word recognition areas of cortex (Dehaene et al., 2001). Identical conscious words triggered higher levels of activity in these areas, but more importantly, they also evoked far more widely distributed activity in parietal and prefrontal cortex. That result has now been replicated more than a dozen times, using different brain imaging techniques and different methods for comparing conscious and unconscious input. Such methods have included binocular rivalry (Sheinberg and Logothetis, 1997), inattentional blindness (Rees et al., 1999), neglect and its extinction (Rees et al., 2002), and different sense modalities, such as audition (Portas et al., 2000), pain perception (Rosen et al., 1996), and sensorimotor tasks (Haier et al., 1992; Raichle et al., 1994). In all cases, conscious sensory input evoked wider and more intense brain activity than identical unconscious input.

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1 Complementary findings come from studies of
 3 unconscious states. In deep sleep, auditory stimulation activates only primary auditory cortex
 5 (Portas et al., 2000). In vegetative states following brain injury, stimuli that are ordinarily loud or painful activate only the primary sensory cortices
 7 (Laureys et al., 2000, 2002). Waking consciousness is apparently needed for widespread of input-driven activation to occur. These findings support the general notion that conscious stimuli mobilize large areas of cortex, presumably to distribute information about the input.

Inner speech, imagery, and working memory

17 Both auditory and visual consciousness can be activated endogenously. Inner speech is a particularly important source of conscious auditory-phonemic events, and visual imagery is useful for spatial memory and problem-solving. The areas of the left hemisphere involved in outer speech are now known to be involved in inner speech as well (Paulesu et al., 1993). Likewise, mental imagery is known to involve visual cortex
 19 (Kosslyn et al., 2001). Internally generated somatosensory imagery may reflect emotional and motivational processes, including feelings of psychological pain, pleasure, hope, fear, sadness, etc. (Damasio, 2003). Such internal sensations may communicate to other parts of the brain via global distribution or activation.

31 Prefrontal executive systems may sometimes control motor activities by evoking motivational imagery, broadcast from the visual cortex, to activate relevant parts of motor cortex. Parts of the brain that play a role in emotion may also be triggered by global distribution of conscious contents from sensory cortices and insular cortex.
 33 For example, the amygdala appears necessary to recognize visual facial expressions of fear and anger. Thus, many cortical regions work together to transform goals and emotions into actions
 35 (Baars, 1988).

The attentional spotlight

45 The sensory “bright spot” of consciousness involves a selective attention system, the ability of the theater spotlight to shine on different actors

on the stage. Like other behaviors like breathing and smiling, attention operates under dual control, voluntary, and involuntary. Voluntary attentional selection requires frontal executive cortex, while automatic selection is influenced by many areas, including the brain stem, pain systems, insular cortex, and emotional centers like the amygdala and peri-aqueductal grey (Panksepp, 1998). Presumably, these automatic attentional systems that allow significant stimuli to “break through” into consciousness, as when a subject’s name is sounded in an otherwise unconscious auditory source.

Context and the first-person perspective

When we step from a tossing sailboat onto solid ground, the horizon can be seen to wobble. On an airplane flight at night passengers can see the cabin tilting on approach to landing, although they are receiving no optical cues about the direction of the plane. In those cases unconscious vestibular signals shape conscious vision. There are numerous examples in which unconscious brain activities can shape conscious ones, and vice versa. These unconscious influences on conscious events are called “contexts” in GW theory (Fig. 1). Any conscious sensory event requires the interaction of sensory analyzers and contextual systems. In vision, sensory contents seem to be produced by the ventral visual pathway, while contextual systems in the dorsal pathway define a spatial domain within which the sensory event is defined. Parietal cortex is known to include allocentric and egocentric spatial maps, which are not themselves objects of consciousness, but which are required to shape every conscious visual event. There is a difference between the disorders of content systems like the visual ventral stream, compared to damaged context systems. In the case of ventral stream lesions, the subject can generally notice a missing part of normal experience; but for damage to context, the brain basis of expectations is itself damaged, so that one no longer knows what to expect, and hence what is missing. This may be why parietal neglect is so often accompanied by a striking loss of knowledge about one’s body space

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1 (Bisiach and Geminiani, 1991). Patients suffering
 3 from right parietal neglect can have disturbing
 5 alien experiences of their own bodies, especially of
 7 the left arm and leg. Such patients sometimes
 9 believe that their left leg belongs to someone else,
 11 often a relative, and can desperately try to throw it
 13 out of bed. Thus, parietal regions seem to shape
 15 contextually both the experience of the visual
 17 world and of one's own body. Notice that neglect
 19 patients still experience their alien limbs as
 21 conscious visual objects (a ventral stream function);
 23 they are just disowned. Such specific loss of
 25 contextual body information is not accompanied
 27 by a loss of general intelligence or knowledge.

29 Vogeley and Fink (2003) suggest that parietal
 31 cortex is involved in the first-person perspective,
 33 the viewpoint of the observing self. When subjects
 35 are asked to adopt the visual perspective of
 37 another person, parietal cortex became differentially
 39 active.

41 *Self-systems*

43 Activation by of visual object regions by the sight
 45 of a coffee cup may not be enough to generate
 47 subjective consciousness of the cup. The activated
 49 visual information may need to be conveyed to
 51 executive or self-systems, which serve to maintain
 53 constancy of an inner framework across perceptual
 55 situations. When we walk from room to room
 57 in a building, we must maintain a complex and
 59 multileveled organization that can be viewed in
 61 GW theory as a higher-level context. Major goals,
 63 for example, do not change when we walk from
 65 room to room, but conscious perceptual experiences
 67 do. Gazzaniga (1996) has found a number of
 69 conditions under which split-brain patients encounter
 71 conflict between right and left hemisphere
 73 executive and perceptual functions. He has
 75 proposed the existence of a "narrative self" in the left
 77 frontal cortex, based on split-brain patients who
 79 are clearly using speech output in the left hemisphere
 81 to talk to themselves, sometimes trying to
 83 force the right hemisphere to obey its commands.
 85 When that proves impossible, the left hemisphere
 87 will often rationalize the sequence of events so as
 89 to repair its understanding of the interhemispheric

91 conflict. Analogous repairs of reality are observed
 93 in other forms of brain damage, such as neglect.
 95 They also commonly occur whenever humans are
 97 confronted with major, unexpected life changes.
 99 The left-hemisphere narrative interpreter may be
 101 considered as a higher-level context system that
 103 maintains expectations and intentions across many
 105 specific situations. Although the inner narrative
 107 itself is conscious, it is shaped by unconscious
 109 contextual influences.

111 If we consider Gazzaniga's narrative interpreter
 113 of the dominant hemisphere to be one kind of self-
 115 system in the brain, it must receive its own flow of
 117 sensory input. Visual input from one-half of the
 119 field may be integrated in one visual hemicortex, as
 121 described above, under retinotopic control from
 123 area V1. But once it comes together in late visual
 125 cortex (presumably in inferotemporal object re-
 127 gions), it needs to be conveyed to frontal areas on
 129 the dominant hemisphere, in order to inform the
 131 narrative interpreter of the current state of
 133 perceptual affairs. The left prefrontal self system
 135 then applies a host of criteria to the input, such as
 137 "did I intend this result? Is it consistent with my
 139 current and long-term goals? If not, can I
 141 reinterpret it to make sense in my running account
 143 of reality?" It is possible that the right hemisphere
 145 has a parallel system that does not speak but that
 147 may be better able to deal with anomalies via
 149 irony, jokes, and other emotionally useful strate-
 151 gies. The evidence appears to be good that the
 153 isolated right prefrontal cortex can understand
 155 such figurative uses of language, while the left does
 157 not. Full consciousness may not exist without the
 159 participation of such prefrontal self systems.

161 *Relevance to waking, sleeping, coma, and general 163 anesthesia*

165 Metabolic activity in the conscious resting state is
 167 not uniformly distributed. Raichle et al. (2001)
 169 reported that mesiofrontal and medial parietal
 171 areas, encompassing precuneus and adjacent
 173 posterior cingulate cortex, can be posited as a
 175 tonically active region of the brain that may
 177 continuously gather information about the world
 179 around, and possibly within, us. It would appear

1 to be a default activity of the brain. Mazoyer et al.
 QA:5 (2001) also found high prefrontal metabolism
 3 during rest. We will see that these regions show
 markedly lower metabolism in unconscious states.

5 Laureys (1999a, b, 2000) and Baars et al. (2003)
 7 list the following features of four unconscious
 9 states, that are causally very different from each
 11 other: deep sleep, coma/vegetative states, epileptic
 13 loss of consciousness, and general anesthesia under
 15 various agents. Surprisingly, despite their very
 17 different mechanisms they share major common
 19 features. These include: (i) widely synchronized
 21 slow waveforms that take the place of the fast
 23 and flexible interactions needed for conscious
 25 functions; (ii) frontoparietal hypometabolism;
 27 (iii) widely blocked functional connectivity, both
 29 corticocortical and thalamocortical; and (iv) be-
 31 havioral unconsciousness, including unresponsiveness
 33 to normally conscious stimuli. Fig. 2 shows
 35 marked hypofunction in the four unconscious
 37 states compared with conscious controls, precisely
 where we might expect it: in frontoparietal regions.

In a related study, John and co-workers showed
 marked quantitative electroencephalogram
 (EEG)² changes between conscious, anesthetic,
 and post-anesthetic (conscious) states (John et al.,
 QA:6 2000). At loss of consciousness, gamma power
 decreased while lower frequency bands increased
 29 in power, especially in frontal leads. Loss of
 31 consciousness was accompanied by a significant
 33 drop in coherence between homologous areas of
 35 the two hemispheres, and between posterior and
 37 anterior regions of each hemisphere. However,
 there was hypersynchronous activity within ante-
 39 rior regions. The same basic changes occurred
 across all six anesthetics,³ and reversed when

39 ²Although the spike-wave EEG of epileptic seizures appears
 41 different from the delta waves of deep sleep and general
 43 anesthesia, it is also synchronized, slow, and high in amplitude.
 45 The source and distribution of spike-wave activity varies in
 different seizure types. However, the more widespread the
 spike-wave pattern, the more consciousness is likely to be
 impaired (Blumenfeldt and Taylor, 2003). This is again marked
 in frontoparietal regions.

47 ³There is a debate whether ketamine at relatively low doses
 should be considered an anesthetic. All anesthetic agents in this
 study were used at dosages sufficient to provide surgical-level
 loss of consciousness.

patients regained consciousness (see John, in this
 volume).

From the viewpoint of globalist theories, the
 most readily interpretable finding is the coherence
 drop in the gamma range after anesthetic loss of
 consciousness. It suggests a loss of coordination
 between frontal and posterior cortex, and between
 homologous regions of the two hemispheres. The
 authors also suggest that the anteriorization of low
 frequencies “must exert a profound inhibitory
 influence on cooperative processes within (frontal) neuronal populations. This functional system then
 becomes dedifferentiated and disorganized” (p.
 180). Finally, the decoupling of the posterior cortex
 with anterior regions suggests “a blockade of perception” (p. 180). These phenomena appear
 to be consistent with the GW notion that wide-
 spread activation of nonsensory regions is required
 for sensory consciousness.

The role of frontoparietal regions in conscious contents and states

Could it be that brain regions that underlie the
 contextual functions of Fig. 1 involve frontal and
 parietal regions? In everyday language, the “ob-
 serving self” may be disabled when those regions
 are dysfunctional and long-range functional con-
 nectivity is impaired. Frontoparietal association
 areas have many functions, but several lines of
 evidence suggest that they could have a special
 relationship with consciousness, even though they
 do not support the sensory contents of conscious
 experience directly. (i) Conscious stimulation in
 the waking state leads to frontoparietal activation,
 but unconscious input does not; (ii) in unconscious
 states, sensory stimulation activates only sensory
 cortex, but not frontoparietal regions; (iii) the
 conscious resting state shows high frontoparietal
 metabolism compared with outward-directed cog-
 nitive tasks; and (iv) four causally very different
 unconscious states show marked functional decre-
 ments in the same areas. Although alternative
 hypotheses must be considered, it seems reason-
 able to suggest that “self” systems supported by
 these regions could be disabled in unconscious
 states. From the viewpoint of the narrative

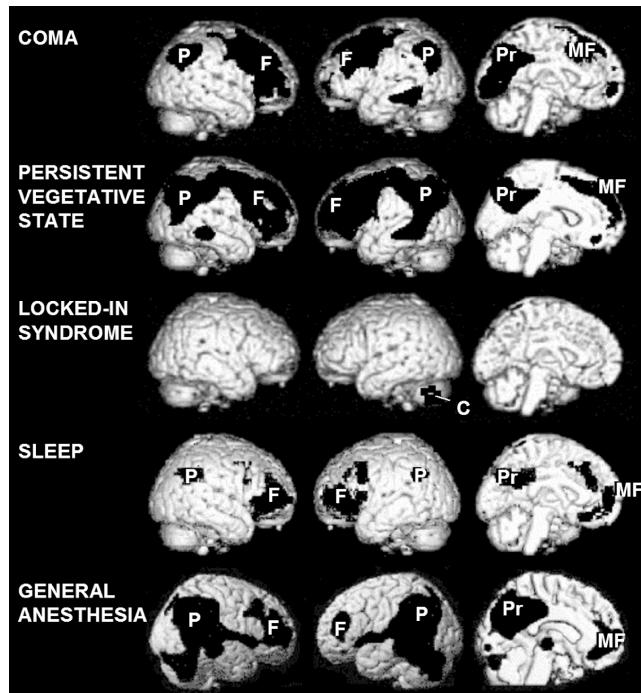


Fig. 2. Neural activity in four types of unconscious states, subtracted from conscious controls. Positron emission tomography scans showing regional decreases in metabolism or blood flow when unconscious states are compared with resting consciousness. Coma, persistent vegetative state, sleep, and general anesthesia all show regional decreases in frontoparietal association cortices. Column 1: the right lateral aspect of the brain; column 2: the left lateral aspect; column 3: a medial view of the left hemisphere. Abbreviations: F, prefrontal; MF, mesiofrontal; P, posterior parietal cortex; Pr, posterior cingulate/precuneus (from Baars et al., 2003).

observer, this would be experienced as subjective loss of access to the conscious world. Unconscious states might not necessarily block the objects of consciousness; rather, the observing subject might not be at home.

Conclusion

GW theory suggests that consciousness enables multiple networks to cooperate and compete in solving problems, such as retrieval of specific items from immediate memory. Conscious contents may correspond to brain processes that work much like brief memories whose contents activate widespread regions in the brain. Physiologically such interactions seem to involve multiple high-frequency oscillatory rhythms. The overall function of consciousness is to provide widespread access,

which in turn may serve coordination and control. Consciousness is the gateway to the brain.

Uncited References

Fiset et al. (1999); Frackowiak et al. (2004); Franklin (2000); Freeman (2003); Tononi and Edelman (1998).

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- 1 References**
- 3 Baars, B.J. (1988) A cognitive theory of consciousness. Cambridge University Press, New York.
- 5 Baars, B.J. (1997) In the theater of consciousness: The workspace of the mind. Oxford, New York.
- 7 Baars, B.J. (2002) The conscious access hypothesis: origins and recent evidence. *Trends Cogn. Sci.*, 6: 47–52.
- QA :8 Baars, B. J., Ramsay, T., Laureys, S. (2003). *Trends in Neurosci.*, 26, 671–675.
- 11 Baars, B.J. and Franklin, S. (2003) How conscious experience and working memory interact. *Trends Cogn. Sci.*, 7: 166–172.
- QA :9 Bisach, E. and Geminiani, G. (1991) Anosognosia related to hemiplegia and hemianopia. In: Prigatano G.P. and Schacter D.L. (Eds.), Awareness of Deficit After Brain Injury: Clinical and Theoretical Issues. Oxford University Press.
- 13 Blumenfeldt, H. and Taylor, J. (2003) Why do seizures cause loss of consciousness? *Neuroscientist*, 9: 1–10.
- 15 Crick, F. and Koch, C. (2003) A framework for consciousness. *Nat. Neurosci.*, 6: 119–126.
- 17 Damasio, A. (2003) The feeling of knowing. Basic Books, New York.
- 19 Dehaene, S., et al. (2001) Cerebral mechanisms of word masking and unconscious repetition priming. *Natl. Neurosci.*, 4: 752–758.
- QA :10 Edelman, G.M. (2003) Naturalizing consciousness: a theoretical framework. *Proc. Natl. Acad. Sci. USA*, 100: 5520–5534.
- 21 Fiset, P., Paus, T., Daloze, T., Plourde, G., Meuret, P., Bonhomme, V., et al. (1999) Brain mechanisms of propofol-induced loss of consciousness in humans: a positron emission tomographic study. *J. Neurosci.*, 19(13): 5506–5513.
- 23 Frackowiak, et al. (2004) Human brain function (2nd ed.). Elsevier, London.
- 25 Franklin, S. (2000) Deliberation and voluntary action in ‘conscious’ software agents. *Neural Network World*, 10: 505–521.
- 27 Franklin, S. (2001) Automating human information agents. In: Chen Z. and Jain L.C. (Eds.), Practical Applications of Intelligent Agents. Springer-Verlag, Berlin.
- 29 Freeman, W.J. (2003) The wave packet: an action potential for the 21st century. *J. Integr. Neurosci.*, 2(1): 3–30.
- 31 Haier, R.J., et al. (1992) Regional glucose metabolic changes after learning a complex visuospatial motor task: a positron-emission tomographic study. *Brain Res.*, 570: 134–148.
- 33 James, W. (1890) The principles of psychology. Holt, New York.
- 35 John, E.R., Prichep, L.S., Kox, W., Valdes-Sosa, P., Bosch-Bayard, J., Aubert, E., et al. (2001) Invariant reversible QEEG effects of anesthetics. *Conscious Cogn.*, 10(2): 165–183.
- 37 Kosslyn, S.M., Ganis, G. and Thompson, W.L. (2001) Neural foundations of imagery. *Natl. Rev. Neurosci.*, 2(9): 635–642.
- 39 Laureys, S., et al. (2000) Restoration of thalamocortical connectivity after recovery from persistent vegetative state. *Lancet*, 355: 1916.
- 41 Laureys, S., et al. (1999a) Cerebral metabolism during vegetative state and after recovery to consciousness. *J. Neurol. Neurosurg. Ps.*, 67: 121.
- 43 Laureys, S., et al. (1999b) Impaired functional connectivity in vegetative state: preliminary investigation using PET. *Neuroimage*, 9: 377–382.
- 45 Laureys, S., et al. (2000) Auditory processing in the vegetative state. *Brain*, 123: 1589–1601.
- 47 Laureys, S., et al. (2002) Cortical processing of noxious somato-sensory stimuli in the persistent vegetative state. *Neuroimage*, 17: 732–741.
- 53 Mazoyer, B., et al. (2001) Cortical networks for working memory and executive functions sustain the conscious resting state in man. *Brain Res. Bull.*, 54: 287–298.
- 55 Moscovitch, M. (1995) Recovered consciousness: a hypothesis concerning modularity and episodic memory. *J. Clin. Exp. Neuropsychol.*, 17(2): 276–290.
- 57 Newell, A. (1994) Unified theories of cognition: The William James lectures. Harvard University Press, Cambridge, MA.
- 59 Panksepp, J. (1998) Affective Neuroscience. Oxford University Press, New York.
- 61 Paulesu, E., Frith, D. and Frackowiak, R.S.J. (1993) The neural correlates of the verbal component of working memory. *Nature*, 362: 342–345.
- 63 Portas, C.M., et al. (2000) Auditory processing across the sleep–wake cycle: simultaneous EEG and fMRI monitoring in humans. *Neuron*, 28: 991–999.
- 65 Raichle, M.E., et al. (1994) Practice-related changes in human brain functional anatomy during non-motor learning. *Cereb. Cortex*, 4: 8–26.
- 67 Raichle, M.E., et al. (2001) A default mode of brain function. *Proc. Natl. Acad. Sci. USA*, 98: 676–682.
- 69 Rees, G., Russell, C., Frith, C.D. and Driver, J. (1999) Inattentional blindness versus inattentional amnesia for fixated but ignored words. *Science*, 286(5449): 2504–2507.
- 71 Rees, G., Wojciulik, E., Clarke, K., Husain, M., Frith, C. and Driver, J. (2002) Neural correlates of conscious and unconscious vision in parietal extinction. *Neurocase*, 8(5): 387–393.
- 73 Rosen, S.D., Paulesu, E., Nihoyannopoulos, P., Tousoulis, D., Frackowiak, R.S., Frith, C.D., et al. (1996) Silent ischemia as a central problem: regional brain activation compared in silent and painful myocardial ischemia. *Ann. Int. Med.*, 124(11): 939–949.
- 75 Sheinberg, D.L. and Logothetis, N.K. (1997) The role of temporal cortical areas in perceptual organization. *Proc. Natl. Acad. Sci. USA*, 94(7): 3408–3413.
- 77 Simons, D.J. and Chabris, C.F. (1999) Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception*, 28(9): 1059–1074.
- 79 Steriade, M. (2001) Active neocortical processes during quiescent sleep. *Arch. Ital. Biol.*, 139: 37–51.
- 81 Tononi, G. and Edelman, G. (1998) Consciousness and complexity. *Science*, 282: 1846–1851.
- 83 Vogeley, K. and Fink, G.R. (2003) Neural correlates of the first-person perspective. *Trends Cogn. Sci.*, 7: 38–42.
- 85 Zeki, S. (2001) Localization and globalization in conscious vision. *Annu. Rev. Neurosci.*, 24: 57–86.

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