Hunting the Ghost: Toward a Neuroscience of Consciousness

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Abstract

Consciousness is a term with many meanings. In one sense, we use the term to indicate whether or not an organism is in a conscious state. In this sense, consciousness is what is altered, reduced, or even lost when we faint or undergo deep general anaesthesia. In a second sense, it is a trait, an attribute of a psychological process; we may think, desire, hear, see, and feel consciously, thereby becoming conscious of thoughts, wishes, voices and music, of colours and textures. Local anaesthesia, by abolishing conscious sensations of touch in the affected limb, thus interferes with the consciousness of something. Within trait consciousness, I draw a further distinction between conscious representations and conscious
access. Conscious representations are of objects or contents of perceptions, desires, or actions; they are usually phenomenal, like a strawberry that is red, sweet, and heart-shaped and that I see, smell, and desire to eat. To describe the strawberry’s looks and taste or to resist its temptation, conscious access to its representation is required (Block, 1995).

This chapter reviews evidence pertaining to the neural basis of state and trait consciousness (Stoerig, 2002). As we (still?) lack an objective marker of conscious representations that is independent of the subjects’ overt behaviour, we can assess conscious representations only when our subjects can access and (verbally or non-verbally) express them. The same applies to the conscious state, because it is only observable conscious access that precludes a diagnosis of unconsciousness. If conscious representations as well as state consciousness are attributed on the basis of evidence for conscious access, the neuronal processes that mediate conscious access in its many forms are likely to contaminate what we learn about those that mediate conscious representations and states. A prominent candidate for mediating conscious access is a network of frontoparietal cortical regions that play an important role in attentional and behavioural selection of incoming and stored information. As these regions allocate processing resources and guide behavioural selection, it is not surprising that they are activated both when vegetative state patients recover and when healthy subjects perform demanding perceptual tasks. Although the frontoparietal network has been implicated in the mediation of the conscious state, of conscious representations, and of conscious access, I argue that these different manifestations of consciousness may well depend on different neuronal processes.
Consciousness as a State of an Organism

Is it possible to identify a system of neuronal structures that mediate all conscious states and whose destruction or downregulation abolishes consciousness? It should be a non-specific system because we are in a conscious state regardless of whether we listen to a concert, indulge in French cuisine, or suffer from heartburn afterward; we are conscious (‘bei Bewusstsein’) regardless of what we are conscious of. Being in a conscious state is prerequisite to any conscious experience, and alterations in the state cause changes in the experience. The following sections discuss sleep as an example of circadian endogenous state changes; general anaesthesia as an example of chemically induced state changes; and comatose, vegetative, and minimally conscious states as examples of pathology-induced state changes. The purpose is to provide up-to-date information on several aspects of consciousness, as well as their interdependence, and to point out some critical confounds.

Sleep

Sleep is regularly and actively induced by a shift in neuronal activity and neurotransmitter balance in brainstem nuclei. In their seminal work, Morruzzi and Magoun (1949) discovered a network of neurons extending from the medulla oblongata through the midbrain up to the diencephalon that seemed to regulate both the activity of the brain and the spinal cord. We now know that three states are balanced within this network: non-REM sleep, characterized by inhibition of the spinal cord and large parts of the cortex; wakefulness, characterized by activation of both; and REM sleep (rapid eye movement sleep) during which the cortex
becomes regionally activated, but the spinal fibres are actively inhibited. This inhibition is crucial to prevent the motor signals that the cortex generates while we sleep from reaching the muscles. A small lesion in the locus coeruleus interferes with this inhibition, so that a sleeping cat, albeit unresponsive to sensory stimulation, exhibits walking or running movements or even full-fledged fighting behaviour (Jouvet & Delorme, 1965); the intact animal will execute only small twitching movements in REM sleep.

In humans, REM sleep behaviour disorders that are a consequence of dysfunctions of the balance between endogenous activation and inhibition come in different degrees of severity. In severe cases, sleepers can be propelled to perform violent actions that endanger themselves as well as their partners and can be most difficult to stop because external sensory input is inhibited during REM sleep and so fails to wake them. Upon awakening and reconnecting with the environment, the patients may report wild dreams that seem consistent with the behaviour they displayed, indicating dream enactment (Schenck, Bundlie, Ettinger, & Mahowald, 1986). A young man recurrently dreamt he was a big cat let out of his cage by a zookeeper who offered him raw meat that he could not snatch. His behaviour during these periods reflected the dream: He would prowl about the house, open the refrigerator with his mouth, or lift a mattress with his jaws and drag it about (Schenck et al., 1989, p. 195).

These REM sleep behaviour disorders differ from non-REM sleep disorders of which sleep walking is probably the best known; sleep eating and sleep sex are other examples (Schenck & Mahowald, 1994). In all of these disorders, the patients initiate seemingly goal-directed activities; they will for instance get up and walk to the fridge, carry the food they find back to bed, and devour it. Clearly, the behaviours are complex, and sequences may last
up to 1 or 2 hours. More tragic results than waking up satiated in a bed messed up with food are evidenced by a series of crimes committed – to the best judgement of the specialists and jury – in this altered state of consciousness (Broughton et al., 1994; Hartmann, 1983). Unlike people awakening from REM sleep behaviours, the non-REM disorder patients usually recall neither a dream nor another aspect of behaviour related to the episodes, indicating that the neurochemistry governing REM and non-REM sleep is likely to differentially affect recall after waking (see Chapter 16 for more information on the neurochemistry of sleep disorders).

The electroencephalographic characteristics of REM sleep – a low-amplitude high-frequency EEG resembling that recorded during waking with eyes open – are suggestive of dream experience. As dynamic, multisensory dreams are reported more often when sleepers are woken from REM rather than non-REM phases, sleep researchers since Kleitman (1963) have tended to equate dream and REM sleep. However, studies that have used more sensitive measures to assess reports of mental activity prior to waking (Foulkes, 1962) have shown that mentation is reported quite commonly after waking from REM as well as non-REM phases (see Table 25.1). Even when woken from the deepest of the non-REM sleep stages, stage 4, which is characterized by a low-frequency, high-amplitude EEG, subjects may report not only some thought-like mentation but also movie-like dreams (see Bosinelli, 1995, for example). The higher incidence of dream reports from REM sleep is a probability effect, not an absolute difference.

Insert Table 25.1 about here
Presently, the EEG is used to classify sleep stages (Rechtschaffen & Kales, 1968), but no physiological marker for the absence or presence of dream mentation has been identified. Therefore functional neuroimaging studies performed on sleeping subjects can provide insights into the regional brain activation patterns that characterize sleep and its different stages, but cannot differentiate between periods with and without mentation. During both REM and non-REM sleep, the prefrontal and parietal cortical regions are deactivated in comparison to the wakeful ‘resting state’ (Braun et al., 1997; Maquet, 2000; Maquet et al., 1996). ‘Resting state’ describes a situation in which subjects lie, with their eyes closed, in the scanner and, despite uncontrolled differences in internally ongoing emotional and cognitive activity, are attentive to the environment. The most active regions in the resting state are the (left) dorsolateral and medial prefrontal areas, the inferior parietal cortex, and the posterior cingulate/precuneus (see Maquet, 2000; Shulman et al., 1997, for reviews). In slow-wave sleep (SWS, non-REM stages 3 and 4 with high-amplitude low-frequency EEG), regional cerebral blood flow decreases in these as well as most other parts of the brain including the thalamus and brainstem; only the perirolandic (sensorimotor) and occipital (visual) cortices were reported to remain unaffected (Kajimura et al., 1999). In REM sleep, despite overall increases in cerebral blood flow and energy demands, relatively low regional cerebral blood flow (rCBF) persists in prefrontal and parietal cortex, whereas relative activations are seen in the brainstem and thalamus where the nuclei that regulate sleep stages are housed (Hobson, 1989; Steriade, 2000; Chapter 16) and in the amygdalae and posterior association cortices (Braun et al., 1997; Nofzinger et al., 1997). Interestingly, the posterior cingulate-precuneal region that is significantly deactivated in both SWS and REM sleep (e.g. Braun et al., 1997;
Maquet et al., 1996) was selectively activated in a SPECT-study of sleepwalking (Bassetti et al., 2000). The increased activity in this posterior midline area in the face of persistent frontal deactivation suggests that this non-REM sleep, and possibly other sleep behaviour disorders, results from pathological combinations of neurobiological features of sleep and wakefulness (Mahowald & Schenck, 2001).

Activation patterns observed during waking and sleeping indicate that the mental activity during sleep differs from that during waking. The observed deactivation of prefrontal cortex seems to preclude neither the sometimes fantastic creativity expressed in dreams nor the cognitive insights that anecdotally occur during sleep. Only recently has the role that sleep plays for the latter been demonstrated experimentally, when subjects were found to be significantly more likely to detect hidden rules to a task when they were allowed to sleep before continuing in its execution (Wagner et al., 2004). The activation of limbic structures and sensory association cortices seen during REM sleep may provide the emotional colour and the multisensory phenomenal content of REM sleep dreaming; both higher auditory and visual cortical areas appear quite reliably activated in this sleep stage.

A further and major difference between waking and dreaming experience/mentation lies in its origin. In the waking state, internal (thoughts, imagery, feelings, memories) and external (sensations) components of mental life shift in their relative contributions throughout the day, but always remain penetrable to each other, whereas in the sleeping state, the external contribution is consistently reduced (see Fig. 25.1). Electrophysiological recordings show that sensory stimuli generate only the early components of the waking state evoked potentials (Yamada et al., 1988), and neuroimaging of responses to auditory
stimulation (text being read to the sleeper) during non-REM sleep produced less auditory cortical activation than in the waking state. In addition, in the visual cortex a pronounced negative BOLD response was seen not only during text reading (Czisch et al., 2002) but also in response to visual stimulation (8 Hz flickering light), and it corresponded to a decrease in rCBF in the same visual cortical areas (rostromedial occipital cortex) in additional volunteers who underwent H$_2^{15}$O PET during SWS (Born et al., 2002). One of the possible interpretations of this finding is that external stimulation interferes with endogenous visual cortex activation.

**Figure 25.1**

![Figure 25.1](image)

*Figure 25.1. The relative contributions of exogenous stimulation (white) and endogenous activity (stippled) to mental life change during the waking period. Here, permeability is considerably higher than during sleep where the contribution of externally induced activity is systematically reduced.*

At present we cannot get information about the experiences of sleepers without waking them and thereby changing their state, and therefore we have no means to determine confidently whether a lack of report indicates a lack of experience or a lack of recall. At the same time, reports need not necessarily reflect mentation just before waking; if there were periods of true nothingness, the reports could also reflect the last event that left a reportable trace. Although the amount and movie-like character of dreams may differ during different
sleep stages and unconscious periods cannot be ruled out, sleep as such is not an unconscious state, but rather one that alters consciousness by closing the shutters on the largest part of external sensory input.

Anaesthesia

General anaesthesia is induced by a variety of very different chemical compounds. This is probably the major reason why, at present, we have no generally accepted theory of general anaesthesia. The major contenders include (1) inhibition of excitatory receptor channels together with potentiation of inhibitory ones that include GABA\(_A\) (\(\gamma\)-aminobutyric acid), glycine, nicotinergic acetylcholine, and serotonin (Franks & Lieb, 1994; 1996); (2) interference with NMDA (N-methyl-D-aspartate) receptor function (Anis, Berry, Burton, & Lodge, 1983; Flohr, 1995, Flohr, Glade, & Motzko, 1998); and (3) changes in polymerization of microtubules (Allison & Nunn, 1968; Hameroff, 1998). Although all these hypotheses focus on some specific cell sites, none implies that a particular brain structure (or set of brain structures) is especially involved in the mediation of the conscious state. It is still open to discussion whether this reflects the fact that core structures that really are indispensable for the conscious state can, possibly due to their central placement, be accessed in very different ways, or whether there are no core structures and the conscious state instead depends on a functional property of the network.

Although earlier neuroimaging data that compared general anaesthesia with pre- or post-anaesthetic states showed that the tested pharmaceutical agents produce an overall reduction in brain metabolism (Alkire et al., 1995), more sensitive analysis revealed that in
addition to the fronto-parietal resting state network, cerebellar, frontobasal, and thalamomesencephalic brain regions are relatively more deactivated (Alkire et al., 2000; Fiset et al., 1999; see Fig. 25.2). Despite some agent-specific differences, the tested anaesthetics – halothane, propofol, and isoflurane – thus produced considerable overlap regarding the most affected brain regions, suggesting the possibility of a central core in the mesencephalic reticular formation and the thalamus (Alkire et al., 2000). Support for a special role of the thalamus and its reciprocal network of connections to the cortex comes from a variety of sources: (1) Functional thalamo-cortical connectivity is altered in anaesthesia (White & Alkire, 2003); (2) the EEG, which at light doses may either increase or decrease its frequency depending on the anaesthetic, changes to slow, large-amplitude patterns at deep levels, indicating thalamocortical synchronization; (3) 3-Hz electrical stimulation applied to thalamic nuclei like the nucleus reticularis thalami during neurosurgery causes behavioural arrest whose appearance resembles the absences observed during certain epileptic seizures; the patient stops responding, looks straight ahead, and cannot remember anything about this 5- to 10-s period after abruptly coming to (Jasper, 1998; Jasper & Droogleever-Fortuyn, 1947); and (4) especially the non-specific thalamic nuclei entertain closely knit connections not only to brainstem nuclei but also to the cortex, the basal ganglia, and the striatum. In view of their central position they are optimally placed to transmit arousal signals as well as exerting both global and local influences on neocortical activity. Originally seen as a dorsal extension of the reticular activating system (Morruzzi & Magoun, 1949), they have been suggested as central players in the mediation of consciousness (e.g. Bogen, 1995; Purpura &
The thalamus, and especially its non-specific nuclei (or neurons, see Jones, 1998), may thus play an important role in maintaining the conscious state.

**Figure 25.2**

Figure 25.2. *The relatively most pronounced effects of propofol (Fiset et al., 1999) are shown together with those induced by halothane and isoflurane inhalation (Alkire et al., 2000). Regional cerebral blood flow was measured in the first and regional cerebral glucose metabolism in the second study. (With kind permission from Michael Alkire).*

Although the overall reduction in brain metabolism effected by the majority of compounds suggests a loss of consciousness, all the problems of ascertaining whether such loss occurs in sleep are exacerbated under anaesthesia: Communication in this state is impossible as the subjects do not respond to verbal commands, and post-anaesthetic recall of events is impeded not only by the drugs and their effects on memory but also by the longer recovery period. Regarding sensory information processing, auditory and somatosensory potentials evoked during general anaesthesia in rats (Angel, 1991, 1993) and humans (Madler et al., 1991; Madler & Pöppel, 1987) show that only the earliest deflections (~10 ms) remain unaffected, whereas mid- and long-latency components are much reduced or absent.
Although this effect is reliably induced with such common agents as propofol and isoflurane and indicates severely altered processing of external stimuli, opioids and anaesthetics like ketamine (a dissociative anaesthetic that in small doses is hallucinogenic and in large ones causes general anaesthesia without immobilizing the subjects or producing the appearance of deep sleep) do not flatten the mid- and long-latency components to the same extent; they may in fact even enhance the amplitude both of the auditory mid-latency and the 40-Hz steady-state response (Plourde, Baribeau, & Bonhomme, 1997). Certainly neurons in cortical as well as subcortical structures do not simply stop responding to sensory signals, as is also demonstrated unequivocally by the fact that a vast part of our knowledge on their response properties stems from anaesthetized animals (Hubel & Wiesel, 1968). Recent neuroimaging data on visual processing in anaesthetized monkeys extend these findings, showing activation in numerous cortical and subcortical structures in response to visual stimuli (Leopold, Plettenberg, & Logothetis, 2003; Logothetis, Guggenberger, Peled, & Pauls, 1999). Human subjects stimulated tactually while undergoing stepped propofol (Bonhomme et al., 2001) or isoflurane anaesthesia (Antognini, Buonocore, Disbrow, & Carstens, 1997) showed that activation in somatosensory cortex is decreased at a lower dosage than thalamic activation. Stroboscopic visual flicker stimulation under pentobarbital produced similar decreases of the BOLD signal in visual cortex, culminating in negative responses in subjects who received the highest doses relative to body weight (Martin et al., 2000). Although at increasingly higher concentration these specific stimulus-evoked responses decrease and eventually disappear (Leopold et al., 2003) and the EEG turns isoelectric, they may remain at the dosage used for clinical interventions.
Behavioural evidence, again from both monkeys and humans, provides further evidence for information processing under general anaesthesia. Ketamine-anaesthetized monkeys can show not only preserved optokinetic nystagmus in response to moving visual patterns but also irregular alternations in its direction when stimuli are presented in binocularly rivalrous conditions (Leopold et al., 2003; see Fig. 25.3). When two patterns moving in opposite direction are presented, one to each eye, the awake subjects’ percept switches in a quasi-regular manner between that of the one and that of the other stimulus (Blake & Logothetis, 2002). This perceptual effect is reflected in the eye movements that follow the perceptually dominant direction of stimulus motion; as they correspond to manual responses given by monkey and human subjects to indicate the perceived direction of motion, they have been used as indicators of perceptual changes in monkeys (Logothetis & Schall, 1989). The presence of optokinetic responses under unambiguous stimulation indicates that sensorimotor loops continue to function at least under relatively light ketamine anaesthesia. More surprising is the finding that these responses switch direction under ambiguous stimulation, because a behavioural pattern that is regarded as evidence for alternations between conscious percepts in the awake organism (Fig. 25.3a) has thus been demonstrated in anaesthetized monkeys.

Figure 25.3
Figure 25.3. Top, When gratings that move in opposite directions are presented simultaneously, one to each eye, the awake monkey, who is trained to indicate motion direction this way, responds by moving the handle alternately into the one or other direction (white and black bars at bottom). The perceptual switches are also reflected in his optokinetic responses that follow the presently perceived grating, as shown both with respect to eye movement amplitude (left axis) and velocity (right axis). The responses consist of alternating slow phases where the eyes follow the perceived motion, and fast phases in the opposite direction. The changes in the direction of the fast phases are easily seen in the velocity plot (grey). Bottom, In the ketamine-anaesthetized monkey, optokinetic nystagmus follows the grating in the unambiguous condition. In the rivalry condition, responses again alternate direction.
The second example concerns memory processes. Numerous studies have investigated memory in patients undergoing surgery under general anaesthesia with a wide variety of agents. Stimulation is usually auditory; the most common paradigm involves reading word lists to the patient intraoperatively. Retrieval of this information is tested postoperatively with indirect methods, such as word-stem completion. In this task, stems of used and new words are presented (as in ‘mem..’), and the subjects are asked to complete these stems with the first word that comes to mind. If overall they use words they have heard during surgery (say ‘memory’ rather than ‘member’) significantly more often than an alternative (and equally common) one, this is regarded as evidence for implicit memory. To distinguish this effect more clearly from explicit recall, Jacoby’s inclusion-exclusion task has been adapted (Bonnebakker et al., 1996): Here, in addition to word-stem completion with the first word that comes to mind, in different series the patients are explicitly asked NOT to use the word they have heard before. Whereas an implicit memory trace may bias a subject’s responses toward repeating what was processed implicitly or explicitly (inclusion), exclusion of this same information requires intentional avoidance of the facilitated word. As this cognitive operation is thought to involve conscious access to the memory, it provides evidence for explicit recall. Remarkably, both inclusion and exclusion procedures as well as two-alternative forced choice (2AFC) have revealed significant memory effects (Bonnebakker et al., 1996), although not every study has yielded this finding. A meta-analysis of 44 studies encompassing 2,517 patients conducted to elucidate the reasons for the divergent results showed that the effect of the stimulation decayed over time. No longer significant 36 hours after surgery, it was highly significant within 12 hours, and still
significant but less so when patients were tested between 12 and 36 hours post-surgery (Mericle & Daneman, 1996).

Together, the studies on information processing under general anaesthesia demonstrate not only dose-dependent specific brain activity in response to stimulation but also significant perceptual (in binocular rivalry) and motor organization (OKN) in ketamine-dissociated monkeys (Leopold et al., 2003), and memory formation in human patients under general clinical anaesthesia. Whether this evidence ought to be seen in the context of unconscious cognition (Mericle & Daneman, 1996) or in the context of information being processed in a state of severely altered, dissociated consciousness still needs to be determined. In the former case – cognition in a state of unconsciousness – we would have to believe that (a) perceptual organization continues to a level at which alternative interpretations of ambiguous stimulations are presented and (b) that memory traces laid down in a state of unconsciousness can be accessed when consciousness is recovered. In the latter case – anaesthesia produces a dissociated state of consciousness – both the perceptual organization and the memory formation would occur in a conscious but dissociated subject.

## Coma and Vegetative State

Coma is a state of unarousable unresponsiveness resulting from severe pathology. The patient lies with the eyes closed and may appear almost as if in deep sleep (see Table 25.2). However, if this state does not end with recovery or death, within weeks the coma will give way to a vegetative state (VS; Jennett & Plum, 1972) that may continue for months or years (persistent VS). In this state, patients “awake” from their coma and may be able to breathe
independently. Importantly, sleep and waking phases alternate in VS (but not in coma), although movies and the popular press often wrongly portray ‘comatose’ patients who sleep restfully for years. Not only does coma not last that long but also VS patients open and close their eyes, react to strong or painful stimulation with eye opening and faster breathing, and may grimace and move their limbs during the waking phases. In addition to pupillary light, cornea, and gagging reflexes, in the waking phases spontaneous movements may be observed; chewing, grunting, swallowing, smiling, teeth gnashing, and brief pursuit eye movements can occur. The state is described as one of ‘wakefulness without awareness’ (Jennett & Plum, 1972).

The vegetative state has recently been differentiated from the newly introduced category of the minimally conscious state (MCS; Giacino et al., 2002). MCS patients may show islands of relatively preserved brain responses (Boly, Faymonville, & Peigneux, 2004; Schiff et al., 2002), as well as fragments of behaviours interpretable as signs of perception and voluntary movement that preclude the diagnosis of vegetative state (Zeman, 1997). Both the vegetative and the minimally conscious state need to be distinguished from the locked-in syndrome in which the patient is fully conscious but, due to a circumscribed brainstem lesion, is unable to communicate in any way other than by lid closure and vertical eye movements. Overall brain metabolism is less reduced in locked-in patients (Levy et al., 1987; see Table 25.2).

Table 25.2 about here
Lesions causing coma, VS, and MCS may be diffuse and metabolic as well as focal. Among the causes for continued loss of consciousness are extensive fibre degeneration, extensive necrosis of the cerebral cortex or the thalamus, and thalamic-hypothalamic and brainstem lesions that involve the pons and its tegmentum (Plum & Posner, 1982). Support for a special role of the thalamus comes from a recent review of pathology data: Of 35 cases of VS caused by trauma, 80% had thalamic damage; in addition, of 14 non-traumatic VS cases, all had severely damaged thalami (Jennett, 2002). Brain metabolism was relatively most affected in frontal and parietotemporal association cortices of VS patients (Kassubek et al., 2003; Laureys et al., 2002a,b, Laureys, Owen, & Schiff, 2004; see Fig. 25.4); in addition, functional connectivity to the intralaminar nuclei of the thalamus was altered (Laureys et al., 2000a). In contrast, the removal of an entire cerebral hemisphere does not cause coma, indicating that the system that mediates the conscious state is bilateral and that one half of a brain suffices to sustain it. Neither does coma result from bilateral lesions that destroy both occipital, both parietal, both temporal, or both frontal lobes.

Figure 25.4
Cortical as well as subcortical activation has been observed in response to auditory (Laureys et al., 2000b) and noxious stimulation of VS patients (Kassubek et al., 2003; Laureys et al., 2002a). The patterns were subnormal and in the case of painful stimuli did not activate the entire pain matrix. In addition, the activated areas’ functional connectivity to the higher frontal and parietal cortices seemed impaired in VS patients, but showed recovery when the patients recovered (Boly et al., 2004; Laureys et al., 2002a). Nevertheless, these data do not preclude the possibility that the VS patients still have some conscious experience even if it is not in context.

Conclusion

The body of data on the three states of altered, reduced, dissociated, or lost consciousness demonstrates how difficult it is to provide incontrovertible evidence for even a transient absence of all consciousness. In all instances, we need to ‘wake’ the person and require a (verbal or non-verbal) report to learn whether anything was experienced before the ‘waking’. Even when this is possible – in sleep or anaesthesia, and to some extent after emergence from VS – the effects of the state change on memory make it difficult, if not impossible, to conclude anything from a negative report. Process fractionation, discussed both in the context of sleep behaviour disorders (Mahowald & Schenck, 2001) and anaesthesia (Cariani, 2000; Mashour, 2004) and referring to dissociations within neurobiological patterns that regulate
the normal stages of sleep and wakefulness, could be extended to the pathological state changes. Such a dissociation-based concept of state changes in general anaesthesia, the vegetative, and the minimally conscious state could accommodate conscious experiences whether or not they are accessible to the subject after ‘waking’ and could explain aspects of wakefulness manifest in vegetative state and sleep behaviour disorder patients.

That the thalamus and its thalamo-cortico-thalamic loops that integrate specific and non-specific neurons (Jones, 1998) play a special role in maintaining state consciousness seems likely in the light of both pathology and anaesthesiology.

Consciousness as Attribute or Trait of Psychological Processes

Even when the organism is in a fully conscious and alert state, it is not capable of being conscious of everything dealt with by its brain. Many brain processes are devoted to the regulation of homeostasis, and at least in humans, hormone secretion, digestion, breathing, immune defence, and the like are in principle unconscious. We can learn about them, but have no direct access to them, and only feel the consequences of their functions and dysfunctions. What the organism can be conscious of depends on its sensory, cognitive, and behavioural faculties. Some of the brain processes involved in their mediation are potentially conscious, in that we can consciously perceive, think, feel, wish, and act upon them. However, at any point in time we are in fact only conscious of a small subset of what we can be conscious of. Despite the richness of our moment-to-moment experience, our
consciousness is limited in its capacity for simultaneous representation. Broadbent’s bottle neck (1974) and Koestler’s administration (1968) metaphors both focus on this restriction, illustrating that only a fraction of what goes on in the brain reaches the top representative.

Neuropsychological Approaches to Conscious Representations

How can we learn in which ways brain processes that can cause conscious experiences differ from those that cannot, and how those involved in mediating the presently conscious differ from those that are potentially, but not now, consciously represented? One of the inroads to the first question is the neuropsychological study of patients or animals who have suffered circumscribed brain lesions. If the lesion destroyed the conscious representation of a particular modality or faculty, we can explore whether implicit (non-conscious) processes remain and how the neuronal activity mediating them and the performance they allow differ from their normal conscious counterparts. The best-known examples of this approach are probably the implicit functions that remain in amnesic and in cortically blind patients.

Claparède (1911) was the first to describe telling evidence of implicit memory. His densely amnesic patient refused to shake his hand after he had, on a previous occasion, pricked her with a needle he had hidden between his fingers. When asked about her refusal, she might even explain that sometimes people hide needles in their hands, indicating that the experience had left a trace that could be incorporated into her behaviour as well as her reasoning; however, she could not consciously recall the original painful episode. Results of extensive formal testing rather than anecdotal evidence have been reported on patient HM whose dense anterograde amnesia resulted from bilateral removal of medial temporal cortex.
A series of papers impressively demonstrates that HM, despite his superior intelligence, was unable to recall or recognize verbal as well as pictorial material if prevented from constant rehearsal between presentation and recall. Nevertheless, HM showed motor learning and from trial to trial improved his ability to trace a line between the double outlines of a star that, like his pencil, were only visible in a mirror. Despite never recalling having performed these tasks before, HM showed similar improvements in solving the Tower of Hanoi puzzle (Cohen & Corkin, 1981; Milner, Corkin, & Teuber, 1968). Another thoroughly studied case, that of KC who suffered extensive bilateral damage involving the hippocampal regions, complements previous findings. He too presents with dense anterograde amnesia, but, unlike HM, is incapable of recollecting episodic memories from his life before the accident, although, like HM, he can recall semantic information from that time. In addition to providing evidence for a dissociation between semantic and episodic memory, he implicitly recovered new associations between word pairs and took longer when responding to rearranged or new pairs than to the original intact pairs, although he failed to recollect the items on explicit testing (see Rosenbaum et al., 2004, for a review). More evidence for implicit memory comes from the work of Warrington and Weiskrantz (1968). They introduced the fragmented figure test and found that their amnesic subjects recognized the figures at an earlier, more fragmented stage when having seen the set before. Other forms of implicit memory include various forms of priming, word-stem completion, and conditioning (Rovee-Collier et al., 2001; Schacter, Dobbins, & Schnyer, 2004; Chapter 28).

Amnesic patients thus provide a prime example of implicit access to information that informs behaviour despite being unavailable to conscious recall. The information – the
pinprick, the word pairs, the fragmented figures – is phenomenally represented as long as it is present, and the patients’ responses to it show that they are perfectly aware of it and able to deal with it in multitudinous ways. The conscious access that manifests itself in their behaviour, however, is lost quickly when the information is no longer present. Implicit memory remains when a form of conscious access – recall – is lost, and thus differs from the second of the widely known examples of implicit functions that survive the lesion-induced loss of their explicit representation, that of blindsight (Weiskrantz, Warrington, Sanders, & Marshall, 1974), where cortical blindness prevents the conscious phenomenal representation of visual information. Cortical blindness results from the destruction or denervation of the primary visual cortex. Patients with absolute field defects consistently claim that they do not see visual stimuli that are confined to the blind field. Nevertheless, they can exhibit non-reflexive visual functions when they are forced to guess whether, where, or what stimulus has been presented and may detect, localize, and discriminate visual stimuli at statistically significant levels (Stoerig, 1999; see Fig. 25.5; Weiskrantz, 1986). Evidence for blindsight has also been reported in hemianopic monkeys (Cowey & Stoerig, 1995) who behaved like the patients; they showed excellent localization performance but nevertheless treated the same stimuli as blanks when given that response option (Stoerig, Zontanou, & Cowey, 2002).

Numerous other examples of implicit visual functions include covert processing of colours in cerebral achromatopsia (Heywood, Cowey, & Newcombe, 1991), faces in prosopagnosia (Bruyer et al., 1983), orientation and size in agnosia (Milner & Goodale, 1995), as well as deaf hearing (Mozaz Garde & Cowey, 2000) and unfeeling touch (Paillard, Michel, & Stenach, 1983) following lesions of the auditory or somatosensory cortices, respectively.
Probably it is fair to say that most every loss that results from a cortical lesion spares implicit functions that can be revealed with appropriate testing.

Figure 25.5

Figure 25.5. In a 2AFC localization task, the hemianopic patient HK performed significantly above chance with a grating contrast of 46% or higher. When asked to indicate whether or not he was aware of the stimulus, which could appear with equal probability at either of the two target positions when he touched the start light shown beneath the fixation cross in the display (left), he did not report awareness on a single trial, regardless of contrast.

Studies of implicit processes and the pathways that mediate them may help us get a better grasp of the neural basis of explicit representations. Blindsight for example seems to involve all the remaining projections from the retina onto subcortical visual nuclei (Pasik & Pasik, 1982) and extrastriate visual cortex (Goebel et al., 2001). The blindness in blindsight can therefore not be attributed to an absence of all cortical involvement, a conclusion supported by evidence for cortical activation in a variety of other neuropsychological
syndromes (e.g., Rees et al., 2000). More likely, some functional or quantitative difference accounts for the loss of the conscious representation. Such loss, albeit of a particular visual feature, also characterizes cerebral colour blindness that results from destruction of the colour complex in the fusiform and lingual gyri (see Meadows, 1974; Zeki, 1990, for review) and cerebral motion blindness that results from bilateral destruction of the motion complex (see Zeki, 1991, for review).

Zeki’s concept of micro-consciousnesses (Zeki, 2001) is based both on the selective loss of visual qualia from circumscribed lesions of visual cortical areas and on the (re)appearance of residual qualia that Riddoch (1917) first observed in the cortically blind fields of some patients. The concerted activity of the early visual cortical areas is necessary to provide the repertoire of our visual qualia – brightness, depth, colour, and motion – that are the phenomenal fabric of conscious vision (Stoerig, 1996). Although the primary visual cortex plays first violin in this concert, as its destruction abolishes all visual qualia in the vast majority of cases, its precise role is still under debate. Certainly functional blindness also ensues when it is disconnected from the higher visual cortical areas (Bodis-Wollner, Atkin, Raab, & Wolkstein, 1977; Horton & Hoyt, 1991). Whether this finding indicates that vision is only conscious when higher visual, and possibly also non-visual, areas receive retinal input via the retino-geniculo-striate–extrastriate cortical route, or whether the normally massive backprojections from higher to earlier visual areas are required for conscious vision, is still uncertain (Hochstein & Ahissar, 2002; Stoerig & Cowey, 1993; Crick & Koch, 1995; Köhler & Moscovitch, 1997; Lamme, 2001). Selective inactivation of feedforward and feedback projections would help disentangle this issue.
Experiments on Normal Observers

How processes that are consciously represented at this moment differ from those that may, but are not, presently so represented has been addressed in normal subjects. The main paradigms manipulate the experimental conditions so that the subjects cannot become aware of parts of the physically presented information; in addition, manipulation of the subjects by means of transcranial magnetic or electrical stimulation is used. Note that unlike the patients who have lost the conscious representation of a sensory modality, the normal subjects consciously perceive information in these manipulations even if they miss whatever target they are seeking. Binocular rivalry, change blindness, inattentional blindness, visual masking, repetition blindness, and the attentional blink are all examples drawn primarily from the visual domain.

Binocular rivalry results from dichoptic stimulation with incompatible images that cannot be fused into a meaningful percept. If one eye sees an upward moving grating while the other sees a downward moving one, rather than perceiving no motion as would happen if the two inputs cancelled each other out, subjects see first upward, then downward, then upward moving gratings in succession. As monkeys also report these changes when trained to indicate upward or downward motion (Logothetis & Schall, 1989), brain processes during rivalrous stimulation have been recorded from both species in the hope that they may help distinguish between processes that are presently conscious and those that are presently not conscious. Results of neural recordings in various areas of the occipito-temporal stream in awake behaving monkeys who constantly indicate which stimulus they presently see have
shown that the number of neurons that follow the percept (rather than responding throughout to the always present stimulus direction they prefer) increase substantially from early to late visual cortical areas (see Fig.25.6). In the motion area MT and in area V4, ~40% of neurons responded to their preferred stimulus only when the monkey indicated seeing it, whereas in inferotemporal (IT) and superior temporal cortex, ~90% of neurons showed this behaviour, indicating that binocular rivalry is largely resolved at this advanced processing stage (Logothetis, 1998).

**Figure 25.6**

*Figure 25.6. In the visual cortical areas of the monkey (top), Logothetis and co-workers recorded neurons’ responses to dichoptically presented stimuli tuned to each area’s*
preferences. Orthogonal orientations were used for V1/V2 and V4, gratings moving in opposite directions for MT (V5), and complex images (face and starburst) for the temporal visual areas TPO and TE. The bars show the proportion of neurons that respond to their stimulus when the monkey indicated perceiving it (black) and when it was perceptually suppressed (grey). Like neurons that responded selectively only during rivalry (darker grey), these were encountered only at the intermediate processing stages V4 and MT. Note that the vast majority of neurons in the highest region investigated fired only when their stimulus was also perceived (with kind permission from Nicos Logothetis).

How do these neurons, which were also found in medial temporal lobe areas of humans (Kreiman et al., 2002), know which stimulus is (or should) just (be) perceived? Do they determine it among themselves, in some kind of oscillating majority vote? If so, do the patterns alternate because fatigue causes the balance to shift to the suppressed population? Or does another brain process determine the perceptual and neuronal switches? Tononi, Srinivasan, Russell, and Edelman (1998) used magnetoencephalography and presented their subjects with dichoptically presented gratings of different colour that flickered at different frequencies to allow attribution of the recorded activity to one or the other grating. In line with previous results (Brown & Norcia, 1997), they found stronger amplitudes correlating with the perceived stimulus. This finding is consistent with more neurons firing in concert, but does not elucidate how the perceptual switches are brought about. Evidence in favour of a switch located outside of the visual areas comes from a neuroimaging study in humans that compared brain activation patterns from rivalrous stimulation with a control condition in which the stimuli were physically alternating so as to produce a rivalrous percept without interocular conflict (Lumer et al., 1998). Such a fake rivalry stimulus is useful for comparison with the real one, because it appears the same to the subject if well done and externally induces the perceptual switches that the subject’s brain initiates on its own under conditions of interocular conflict. The results of the comparison of activation patterns evoked
by real and fake rivalry indicated that a frontoparietal network was more active in real rivalry. That a frontoparietal network may be involved in initiating the perceptual switches agrees with observations in patients with damage to the right frontal lobe who may fail to report perceptual alternations of ambiguous figures (Ricci & Blundo, 1990). Leopold and Logothetis (1999) use this finding to back their hypothesis that the (frontoparietal) sensorimotor systems punctuate the visual areas and thereby actively shift the perceptual interpretation by means of attention poised for action.

Frontal regions have also been implicated in change blindness. Here, two complex visual stimuli, such as photographs of real-world scenes or arrangements of symbols, are presented in alternation. The two stimuli are similar overall, but differ in some feature; a person may wear a different pair of trousers, or a mountain may shift position. In between stimulus presentations, a blank screen appears briefly to simulate an eye blink and mask the transient change, rendering change detection difficult enough for subjects to require several cycles of presentation (Rensink, 2000; Simons & Levin, 1997; see Chapter 9). Beck and colleagues (2001) used this phenomenon in a neuroimaging study in which they substituted one image of a face (or a place) for another. They compared activation patterns correlating with stimulus presentations yielding change detection with those in which the change went unreported and found significant differences in frontoparietal (right middle frontal gyrus and bilateral superior parietal lobule) activation. Here, activation was pronounced when the change was detected, whereas the visual areas that are responsive to faces, or places, respectively, appeared not to differentiate between detected and undetected changes.
Results based on a variety of paradigms (e.g., detection of threshold stimuli; (Pins and ffytche, 2003) or detection of a moving target in a field of relative cortical blindness (Sahraie et al., 1997)) support the hypothesis that frontoparietal networks play some role in conscious vision. However, they do not address whether frontoparietal neurons play an important part in the phenomenal rendering of the information and, if they do, which neurons are implicated. Conceivably, all or some of these activated neurons are involved in attentional selection, and again all or some of them may be required to provide conscious access to that information. As detection is inferred on the basis of report, and both attention and access are necessary for report, it is premature to ascribe the conscious detection of stimulus or change to the frontoparietal regions.

Some light is shed on this issue by recent studies. An attentional blink paradigm was used in the first such study. In this ‘experimental blindness’ paradigm, different visual stimuli are presented briefly and in rapid alternation, and two targets are embedded in the series. Although the targets differ in some prominent feature from the distractors – they may be white letters when the distractors are black letters – subjects’ detection of the second stimulus is severely impaired provided the second stimulus follows the detected first target after a (distractor-filled) interval of ~100–300 ms (Chun & Potter, 1995). Marois, Yi, and Chun (2004) found that activity in the parahippocampal place area (PPA) was enhanced when the second of the two target stimuli (a scene) embedded in a rapid series of scrambled versions of the same scenes that served as distractors was consciously perceived; moreover, frontal cortex was activated only when the target was also reported. Whereas the first finding indicates that the PPA, which responds preferentially to images of places and houses, is
activated differentially when the appropriate stimulus is consciously perceived, the latter result implicates the frontal activation in report.

This result gains support from a change detection study. Here, subjects had to maintain a sample stimulus in short-term memory in order to decide whether the test stimulus, which appeared 6 s later at the same central position, matched the sample (Pessoa & Ungerleider, 2004). Importantly, the authors used a stimulus/response-contingent analysis of their imaging data, contrasting false alarms (reports of a change that had not occurred) with misses (missing a change that had occurred), as well as hits (correctly reporting a change) with correct rejections (correctly denying a change). In this fashion, they could show that, albeit less strongly, false alarms activated the same frontoparietal network as hits. Missed targets produced less (Marois et al., 2004) or none of this dorsal frontoparietal activation even if subjects indicated high confidence in their responses (Pessoa & Ungerleider, 2004). Instead, focal activation increases were seen in visual areas tuned to the stimuli and in more ventrally situated frontal areas (inferior frontal gyrus: Beck et al., 2001; supplementary eye field: Pessoa & Ungerleider, 2004).

That different brain regions are involved in different aspects of processing, such as phenomenal rendering, report, and attention, is thus more than a conceptual possibility. Moreover, different neuronal populations in the same area also seem to be differentially involved, as indicated by physiological recordings in the frontal eye field (FEF) of monkeys performing a detection task in which a proportion of targets was masked (Thompson & Schall, 2000). Reminiscent of Pessoa and Ungerleider’s results, the authors found FEF neurons that responded when the monkeys reported a target, regardless of whether the target
had been presented or not. However, visual FEF neurons that do not project to oculomotor structures also showed a selective post-mask activity that was synchronized to target presentation. These neurons may send feedback to extrastriate visual cortex, prompting and questioning them as prefrontal cortex has been suggested to do in several ambiguous and difficult visual tasks. Finally, transcranial magnetic stimulation over the FEF in humans improved the subjects’ detection of backward masked targets when delivered 40 ms before target onset (Grosbras & Paus, 2003). As electrical microstimulation of the FEF in monkeys has been shown to enhance the visually evoked responses in area V4 (Moore & Armstrong, 2003), this finding is in line with a frontal ‘prompting’ of visual areas as well as a gain effect (i.e., an enhancement of visual responsivity as has been repeatedly demonstrated to result from attention).

In difficult tasks, such as those used for studying processes pertaining to presently invisible or inaccessible information in normal subjects, attention is certainly required. In its different guises (focal, spatial, divided, voluntary, automatic), attention can modulate the activity of sensory neurons (Desimone & Duncan, 1995) even in the absence of stimuli (Kastner et al., 1999), affect the apparent contrast of stimuli that are presented (Carrasco, Ling, & Read, 2004), and enhance spatial resolution and recognition. Depending on guise and context, attention invokes different subcortical and cortical neural networks including dorsal and ventral frontoparietal regions (Corbetta & Shulman, 2002). It may thus account for some aspects of the different stimulus- and response-contingent activation patterns in the change detection and attentional blink results.
Because the effects of attention permeate the entire perceptual process from the phenomenal rendering through recognition and working memory to report of stimuli, its neuronal correlates require careful differentiation from those involved in consciousness. This is both important and difficult. It is difficult because, as just described, attention affects the structures that are involved in perceptual processing. It is important because attention is distinct from consciousness: Like sensory information processing, but unlike consciousness, attention comes in covert as well as explicit forms, being automatically deployed in the first, and intentionally focussed in the second. That voluntary focal attention can be required for above-chance performance in tasks in which the stimuli are not consciously perceived – masking in normally sighted subjects is one example (Naccache, Blandin, & Dehaene, 2002) – further underlines its being different from the conscious representation.

Conclusion

Whether information, which is processed to an extent that makes it behaviourally effective, becomes consciously represented is not determined by attention alone. In the absence of sufficient visual information, as in blindsight or under stringent masking conditions, attention cannot render the representation phenomenal. Both attention and the conscious access to the information that is required for the subjects to be able to communicate that they have a conscious representation of the information invoke frontoparietal cortices. Although their role is thus of great importance in establishing whether a representation is conscious, the process that renders it phenomenal requires the functionality of the systems that provide the information. In the present vision-only examples, it is the destruction or denervation of the
visual cortices, rather than that of frontoparietal circuits, that abolishes (aspects of) phenomenal vision or object recognition dependent on what parts are affected. The jury that decides whether these regions are only necessary, as people who argue that it is only by virtue of access that conscious representations are formed contend (see below), or whether they are also sufficient is still out.

Consciousness and Confounds

The neural correlates of conscious sensations and representations depend on many factors. The stimulus itself is one; presentation of a brief beep causes a cascade of brain events that is different from that caused by a briefly presented red blob, and the neuronal response to a red blob depends on stimulus size, position, contrast, and so on. The experimental conditions under which the stimulus is presented – whether it is a singleton, or presented simultaneously with distractors, or in a series of other stimuli – will also influence both the neuronal response it evokes and its detectability. The subjects’ task bears on the level of processing that a stimulus achieves; for example, detection of face stimuli among non-face distractors requires a level of processing different from what is required for recognition of individual faces. What the subject senses or experiences depends on the magnitude and probably the kind of neuronal response; the strength of the response, the size of the activated population, and whether its members act in concert are all likely to play a role. What becomes consciously represented may depend on what the subject attends to, and attention invokes extravisual structures that in their turn affect visual neurons. What becomes consciously represented may also depend on the subject’s alertness; some events pass unnoticed when
one is daydreaming, whereas others, like slipping on a banana skin, reach consciousness if anything does. Whether anything becomes consciously represented depends on the subject being in a conscious state in the first place. Neuronal processes involved in mediating the conscious state, whether via the reticular formation, or through non-specific thalamo-cortico-thalamic loops, or through some other type of process, provide the critical background for any conscious representation. It is therefore not surprising that manipulations of non-specific brain structures alter the stimulus-driven activity of specific neurons (Jasper, 1949) as well as neuronal networks (Munk et al., 1996); Bachmann’s approach to the microgenesis of conscious perception takes this non-specific thalamic-enabling effect into account (Bachmann, 2000).

If all of these factors, and the list is not exhaustive, determine what gets to be represented and also to what depth it does so, it is a hard task to define the neural correlate even of a single phenomenal sensation. To make matters worse, observers who want to study conscious processes require a report from the subject that they can confidently use to assert that something was consciously seen, heard, or felt. In view of the possibility of implicitly guided motor behaviour, this (verbal or non-verbal) report cannot be of a kind that could also be elicited when no conscious representation was formed. Giving an unequivocal report requires not only sufficient motor control on the part of the subject but also conscious access to his or her phenomenal percept. In Block’s definition (1995), ‘access-consciousness’ is availability for use in reasoning and rationally guiding speech and action. Conscious access and reportability are the ones most likely to involve additional neuronal processes, which further encumbers the search for the neuronal correlates of trait consciousness, especially if
neither access nor reportability is necessary for having the experience in the first place. This point – whether or not access is necessary for the phenomenal representation – is controversial (Block, 1995, 2005; Rosenthal, 1986; Stoerig & Barth, 2001).

Studies tackling the neural substrate of conscious representations indicate that the sensory systems are necessary for the phenomenal rendering of stimuli. However, their activation as such can be insufficient to generate conscious sensation, as demonstrated by the finding that implicit and explicit perceptual processes are mediated by overlapping sensory regions, suggesting that a certain level, type, or pattern of activity is necessary. To what extent non-sensory cortical networks are required for phenomenal perception is still unresolved (see discussion in Köhler & Moscovitch, 1997). My working hypothesis is that the sensory neurons’ concerted activity is responsible for providing conscious phenomenal content; reflecting on this content could well be enabled by non-sensory networks that also access the sensory ones during recall and imagery and prompt them continuously – challenging the consistency of their report and requesting different interpretations in the face of ambiguous input. The frontal cortex is indispensable for conscious report because voluntary behaviour is impossible without it, but any interference with reportability is moot regarding the presence or absence of a phenomenal representation.

This argument extends to the interpretation of data from patients in pathological states of consciousness. A marked decrease in frontoparietal network activity is consistent with the patients’ inability to give consistent reports about any experiences they may have, but does not preclude that they have any. Functional disconnections between sensory and frontoparietal areas as inferred from neuroimaging of vegetative state patients agree with this
cautious interpretation. In fact, the functional neuroanatomy of sleep in its various stages provides experimental support for it, as both REM and non-REM sleep are characterized by a decrease in frontoparietal activation, although extended periods of sleep brim with phenomenal experiences. Although these experiences are not lacking in vividness, they are lacking in immediate and general reportability and other forms of access. If access consciousness depends on phenomenal consciousness, there is no access if the phenomenal representation is lost; but if access is lost while phenomenality remains, only the subject learns about it.

The multiplicity of conjoined factors is likely to contaminate the conclusions we draw from the experimental data. To un-confound them, we need a means to establish whether something is consciously represented, a means that, like a brain potential or some other physiological marker, is independent of a behavioural response. As yet, we do not know whether someone is conscious at all unless he or she displays behaviour we are able to identify as consciously initiated, and we do not know whether something is consciously represented unless he or she informs us about it. Only people who equate access and phenomenal consciousness need not mind what to the others appears a barrier large enough to warrant a Nobel prize to reward its dissolution.

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References


Braun, A.R., Balkin, T.J., Wesensten, N.J., Carson, R.E., Varga, M., Baldwin, P., Selbie, S., Belenky,


Table 25.1: The incidence of dream reports is lower when subjects are woken from non-REM sleep; absolute values depend on which non-REM stage preceded the waking, and what is counted as a dream.

<table>
<thead>
<tr>
<th>Authors</th>
<th>% dream reports from REM</th>
<th>Non-REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aserinsky &amp; Kleitmann, 1953</td>
<td>74</td>
<td>22</td>
</tr>
<tr>
<td>Dement &amp; Kleitmann, 1957</td>
<td>79,6</td>
<td>7</td>
</tr>
<tr>
<td>Foulkes, 1962</td>
<td>87</td>
<td>74</td>
</tr>
<tr>
<td>Hobson et al., 1965</td>
<td>87,2</td>
<td>37,2</td>
</tr>
<tr>
<td>Kales et al., 1967</td>
<td>83</td>
<td>35</td>
</tr>
<tr>
<td>Foulkes and Schmidt, 1983</td>
<td>93</td>
<td>67</td>
</tr>
<tr>
<td>Cavallero et al., 1992</td>
<td>89,2</td>
<td>64,5</td>
</tr>
<tr>
<td>Bosinelli, 1995</td>
<td>89/93</td>
<td>65/77</td>
</tr>
<tr>
<td>Cicogna et al., 2000</td>
<td>93,33</td>
<td>62,62</td>
</tr>
<tr>
<td>Nielsen, 2000</td>
<td>81,9 +/- 9</td>
<td>43+/-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20,8</td>
</tr>
</tbody>
</table>
Table 25.2: Overview of best-possible behaviours observed in pathology-induced state changes.

<table>
<thead>
<tr>
<th>State</th>
<th>Coma</th>
<th>VS</th>
<th>MCS</th>
<th>Locked-in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive eyeopening</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cyclic eye opening</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Verbal utterances</td>
<td>Grunts</td>
<td>Jumble</td>
<td>Intelligible</td>
<td>No</td>
</tr>
<tr>
<td>Motor behaviour</td>
<td>Reflex</td>
<td>Reflex</td>
<td>In context</td>
<td>No (eyes only)</td>
</tr>
<tr>
<td>Affective behaviour</td>
<td>No</td>
<td>Yes</td>
<td>In context</td>
<td>No</td>
</tr>
<tr>
<td>Breathing</td>
<td>Variable</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>EEG</td>
<td>δ, τ, slow α</td>
<td>α, local γ</td>
<td>Almost normal</td>
<td></td>
</tr>
<tr>
<td>Brain metabolism (overall)</td>
<td>50%</td>
<td>~50%</td>
<td>~40%</td>
<td>Small-medium reduction</td>
</tr>
<tr>
<td>Pain experience</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Self</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
In both VS and MCS patients, stimulation may evoke local brain activation patterns. Note that negative statements on pain experience and self-consciousness are only inferred from the behavioural response patterns.