Consciousness is an active process with multiple components. The ascending reticular activating system has multiple anatomical and neurochemical components in the rostral brainstem tegmentum, thalamus, and cortex, and is responsible for alertness, a prerequisite for maximal awareness. Awareness also has multiple facets. Sensations, after initial reception in the cortex, are further selected and processed in connected regions. Perception involves the abstraction of selected sensory information, allowing a limited concept of what is happening in the external world and within the body. Attention directs and selects certain information to the exclusion of others. Information is transiently held in working memory to allow for immediate action and decisions. Some forms of memory are accompanied by conscious awareness that is proposed to be necessary for the provision of a sense of continuity in everyday life. Motivation is involved with prioritizing and choosing behavior. The brain also has the capacity for self-awareness, ie, awareness that one has certain cognitive and mental processes. Cognition or thought, traditionally at the “highest level” of cognitive functioning (eg, deductive reasoning), involves the synthesis of the above-listed components.

William James' defined consciousness as awareness of oneself (or one's own cognitive experience) and the environment. This apparently simple definition belies complex brain functions that involve numerous discrete, if interrelated, qualities and components. These components and their anatomical substrates are illustrated in the Figure. We discuss the 2 major components, alertness and awareness, separately, although they are strongly interconnected. Within each there are, again, multiple elements that will be individually addressed.

ALERTNESS

The alertness or wakefulness component is dependent on the ascending reticular activating system in the upper brainstem tegmentum and midline and intralaminar nuclei of the thalamus (Figure).² This system extends through to the cerebral cortex. The ascending reticular activating system was initially thought to be an undifferentiated collection of neurons with extensive internal connections and projections both rostrally and caudally. Further studies on the morphological features, connections, and neurochemistry of its separate cell groups revealed that they have distinct properties, as well as being components of the arousal system. The thalamic reticular nucleus is responsible for “gating” specific reticular information that is transmitted to the cerebral cortex and provides feedback to the brainstem centers that play a role in arousal and alertness. Thalamic gating is likely relevant for attention and concentration, in which selection is an important component.

The principal neurotransmitter systems relevant to arousal are cholinergic, monoaminergic, and γ-aminobutyric acid-ergic. Glutamic and aspartic acids, intrinsic cortical neurotransmitters, play a key role in the excitatory synaptic activity in the cortex, in corticofugal projections, and in at least some thalamocortical af-
The effects of anatomical lesions provide further insight. Most coma-producing strokes involving the brainstem are related to occlusion of the basilar artery with the most caudal lesion in the midpontine tegmentum at the level of the trigeminal outflow. Transection of the brainstem at the midbrain level results in permanent coma. An extreme example of alertness without awareness is the patient in a persistent vegetative state. The patient can be aroused from sleep, with eye opening and electroencephalographic arousal, but there is no perception, comprehension, meaningful interaction, or behavioral response. Awareness requires cerebral cortical activity that is intimately connected to that of subcortical structures. An electrophysiological phenomenon, the gamma or “40-Hz rhythm,” is produced by thalamocortical circuits during attention and sensory processing tasks that require binding of processed sensory information with memory, attention, and motor responses. This rhythm is synchronous across various regions, linking thalamocortical networks as well as the hippocampus and neocortex. It has been proposed that such coherent rhythms allow a timing reference that fosters simultaneous or parallel brain activity in a network rather than purely hierarchical fashion. In this way, for example, all modalities of an object held in memory can be appreciated.

AWARENESS

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Awareness of perception and the creation of thought processes are at the highest levels of conscious behavior. In discussing consciousness, we are forced to artifi-
cially select and isolate certain components (Figure) that are intimately connected with each other and the ascending reticular activating system.

Sensation and perception appear to be parallel but interdependent activities. Sensation is necessary to allow for conscious appreciation. Sensation involves the awareness, on the part of the individual, of something happening as a result of a stimulus acting on a sensory receptor. Sensations have discrete (modular) primary cerebral cortical–receiving regions and association areas for processing (Figure). Primary sensory modalities include visual, auditory, somatosensory, olfactory, gustatory, vestibular (sense of movement), and visceral sensations. Sensations have temporal (timing relative to the present) and spatial (reflecting the part of the body affected) characteristics and are modality specific (eg, visual sensation is distinct from somatosensory stimulation, even if both refer to the same extrapersonal object). There are both forward and backward interconnections between the various regions involved in sensory processing; ie, the system is not a 1-way hierarchical system from primary sensory cortex to other regions without considerable interaction involved in processing. Both serial (hierarchical) and parallel processing of information occur. Sensations are linked with memory and affect to allow recognition and appreciation of their significance.

Perception involves further processing of sensory information, allowing a symbolic concept of what is happening in the external world. Usually perception overrides sensation when both are present, such that we are less aware of what is happening to ourselves than our interpretation of what is happening in the outside world. Object vision involves the ability to segment the image into background and foreground and to fuse the impressions into shapes and objects. Conscious vision involves object recognition, a complex process involving the primary visual cortex, visual association areas, and reciprocal connections with memory stores. It is likely that meaning and significance are given to parallel and serially processed sensory information by feedback and feedforward connections involving multiple hierarchical levels. Lesions that destroy or isolate the primary visual cortex, but spare the extrageniculostriate pathways and extrastriate cortical areas, still allow behavioral reactions to unseen visual stimuli, resulting in a phenomenon known as blindsight. Such individuals can make accurate projections into a visual field for which there is no sensation of vision, but deny conscious awareness of the existence of the object in extrapersonal space. The information is thus processed to a considerable extent, despite not being consciously perceived.

Attention forms a component of perception, in that it accounts for the selection and directed concentration on processing certain information with the exclusion of other competing stimuli or data. The prefrontal regions play an important executive role in choosing the information to be consciously perceived, with further processing and linkage to other functional modalities, including memory and motivational regions and motor areas.

ATTENTION

Moscovitch’ defined attention as, a control process that enables the individual to select, from a number of alternatives, the task he will perform or the stimulus he will process, and the cognitive strategy he will adopt to carry out these operations.

As a prerequisite, the individual must be awake and alert. Attention’s main features include directivity and selectivity of mental processes. There is a close physiological relationship between alertness, attention, and perception.

Brain structures that subserve attention include the anterior cingulate gyrus, the dorsolateral prefrontal cortex, the inferior parietal lobe, the centromedian and parafascicular thalamic nuclei, the thalamic reticular nucleus, the reticular formation of the midbrain tegmentum, and the superior colliculus. Unilateral lesions of the mesencephalic tegmentum can result in neglect of contralateral hemispace, possibly because of diminished activation of more rostral structures. The dopaminergic and noradrenergic systems are important in attentional responses. Motor inattention results from lesions of the dorsolateral frontal region. Akinetic mutism, a condition in which the animal appears awake, but does not respond to stimuli, can be produced by lesions of the centromedian and parafascicular thalamic nuclei.

MEMORY

Hebb, who inspired much of the progress in neurophysiological research and cybernetic modeling of brain activity involved in processing information, proposed the following for associative learning: when an axon of a cell A is near enough to excite a cell B and repeatedly and persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A’s efficiency, as one of the cells firing B, is increased. Thus, enhancement of synaptic connections or functional mechanisms likely underlies various forms of learning and memory.

Memory function is composed of distinct subsystems, some of which are involved in consciousness. Although working memory has been described in a variety of ways, a common definition is the short-term retention of a limited number of items held in consciousness for immediate use. Lesions of the prefrontal cortex in monkeys have been found to compromise visuospatial working memory. Remote or retrograde memories are subserved by different neural systems than those involved in laying down new (anterograde) memories. This distinction was originally made by Scoville and Milner who studied a patient whose medial temporal structures were resected bilaterally. This resulted in a loss of anterograde memory, but a relative preservation of remote memories (laid down before the resection). A number of structures have been identified that compose the circuit for anterograde memory: the hippocampus, the parahippocampal gyrus, the subiculum, the entorhinal and perirhinal cortex, the mammillary bodies, the dorsomedial! thalamic nucleus, the cingulate cortex, the fornix, and fiber tracts connecting these structures (Figure).
Even profoundly amnestic subjects, like the patient of Scoville and Milner, can learn, retain, and retrieve certain material without recollecting the experience (implicit memo). Examples include the acquisition of new sensorimotor skills or the recovery of information about specific items, if appropriate cues are provided. Implicit memories apparently are not mediated by hippocampal structures but are processed and elaborated elsewhere. An amnestic individual, without the ability to store conscious, explicit memories, cannot be considered to be unconscious, in that alertness is preserved and the individual still interacts with the environment. However, an important component of mental activity that allows the conscious linking of the past and present is missing.

Moscovitch\textsuperscript{11} proposed that explicit, but not implicit, memories are accompanied by consciousness. The explicit nature of the recall relates to the binding and integration of neural events by the hippocampus and related structures. Consciousness is bound to the information-containing elements of the explicit memory trace and is recovered along with the memory. Conscious recollection is constantly occurring and provides us with a sense of familiarity and continuity. In contrast, the patient without current explicit memory has been described as “isolated in a single moment of being, with a moat of lacuna all around him. . . . He is a man without a past (or future) stuck in a constantly changing, meaningless moment.”\textsuperscript{12}

**THE MOTIVATIONAL SYSTEM**

Motivational drives help to determine behavior, once the person or animal has attended to the stimulus and assessed its significance relevant to competing internal or external factors. The motivational system is closely allied to crude consciousness, perception, goal-directed activity, and emotions. Emotional cognition, including motivation, depends on a network of structures, limbic and nonlimbic, and neurotransmitter systems, and cannot be isolated to a single, independent entity.

Important structures in the generation of internal feelings and motivation are the amygdala, hypothalamus, and associated limbic structures. The hippocampus and amygdala on each side of the brain receive parallel-convergent projections from the various sensory systems. The hippocampus consolidates the information into memory and accesses stores of recent memory in the neocortex.\textsuperscript{13} The amygdala, by its connections with various cortical structures, gives the sensory information an affective and experiential tone as well as the expression of emotion through its connections with the hypothalamus.\textsuperscript{14} Other limbic structures also play a role in emotional experience and behavior. Lesions of the posterior insula cause pain asymbolia, in which painful stimuli are not emotionally perceived or acted upon.\textsuperscript{15} This may relate to a disruption in the multisynaptic connections between the limbic system and the neocortex.

The hypothalamus plays a major role in the outward expressions of emotion—autonomic phenomena and behaviors. This small diencephalic structure receives afferents from various parts of the brain, including other components of the limbic system (both the amygdala-diencephalon and hippocampal-forniceal-mammillary subdivisions), the cerebral cortex, and the reticular formation. The hypothalamus is also sensitive to the internal milieu of the body and is largely responsible for maintaining homeostasis through endocrine, autonoma, and behavioral inputs and outputs. The diverse functions of the hypothalamus are related to final pathways for various activities of importance to the organism.

**COGNITION AND THE FOCUSING OF AWARENESS**

Cognition, like consciousness, is difficult to define satisfactorily. Thought depends on all the components of consciousness discussed earlier and also includes an awareness of one’s own cognitive activity, although we are only aware of some of the operations and the results of cognitive processing.\textsuperscript{16}

Several models have been proposed to explain the focusing of cognitive awareness. One of the simplest is the “Cartesian theater,” which postulates a single locus of awareness through an internal viewing mechanism.\textsuperscript{17} However, there is no anatomical or physiological evidence for such a single site of awareness.

A more plausible model involves a network of numerous interconnected modular processors across vast regions of cerebral cortex (with reciprocal connections with subcortical structures) that provide parallel processing of information. Kinsbourne\textsuperscript{18} proposes that the most widespread coded neuronal activity is the one that achieves consciousness at that time, the dominant neuronal action pattern or dominant focus hypothesis. Some phenomena, eg, pain, may have a powerful overriding influence. A dominant focus is one that drives other regions in synchronous neuronal firing or rhythms. If this reaches a critical size, it is perceived as consciousness.

A limited capacity system may allow for the finite information that we can attend to and hold in working memory at any one time.\textsuperscript{19} Baars\textsuperscript{20} proposes that the brain works in a manner similar to global workspace computer models, allowing competition of a number of parallel processes. Selected activities achieve conscious awareness. He proposed that the reticular-activating system of the brainstem and the reticular nucleus of the thalamus are examples of biological systems that work on this principle; these together, plus other systems, eg, parietal and temporal cortical regions, may be necessary and sufficient for this model.

Additionally or alternatively, a focusing system to allow sustained cognition may receive direction from an executive (frontal lobe) region, rather than processed streams merely competing among each other.\textsuperscript{21} The executive function of the frontal lobes impacts on many aspects of conscious experience. Knight and Grabowecky\textsuperscript{22} describe patients with prefrontal damage who showed behavioral deficits including the loss of inhibitory control and novelty detection, leading to distractibility, a noisy internal milieu, impaired attention, poor temporal coding, and lack of sustained cognitive function. Thus, in daily life, these individuals are impaired in their conscious evaluation and appropriate behavioral adjust-
ment. Moscovitch\textsuperscript{11} proposes that efficient memory functioning that is integrated into focused cognitive activity, involves self-organization, strategic intervention, and monitoring. The frontal lobes are believed to organize input, devise retrieval strategies, verify output, and place it in the proper historic context. Prefrontal regions then use this information to provide further mnemonic searches and to direct and plan further action.

Aspects of cognitive awareness are probably not diffusely and homogeneously distributed throughout the brain. Lesions of the frontal, inferior parietal, and superior temporal regions disturb the integration of cognitive and affective components of awareness.\textsuperscript{13} The recognition and awareness of parts of one’s self or the environment may be seriously compromised, at least acutely, by nondominant parietal lesions that are often accompanied by hemianopsia, disorientation, mood disorder, and impaired abstract reasoning. Lesions of primary sensory areas in themselves usually do not cause such loss of awareness of the body, space, or of the deficit itself. Lesions of multimodal processing regions are probably necessary for this to occur.

At a higher level, self-awareness which includes self-esteem, the concept of the distinctiveness of oneself from the rest of society, and, more introspectively, of one’s own thoughts (covertness) are aspects of consciousness.\textsuperscript{14} The brain’s functions of self-awareness evolve ontologically and are likely supramodal, ie, are functionally above the unimodal and multimodal processing units.\textsuperscript{16,21}

Language function is a highly developed cognitive activity of great human importance. The left temporoparietal region plays an important function in converting processed information into symbols in the form of language, allowing for internal conversation and conceptual formulation. However, severely aphasic individuals are still alert and aware and can interact with others in meaningful and complex ways; language function is therefore not essential for human cognition.

FUTURE DIRECTIONS: THEORETICAL AND PRACTICAL APPLICATIONS

A fusion of neurophysiological, philosophical, and psychological concepts may lead to a closer understanding of consciousness. In any case, a scientific revolution with a shift of paradigms (accepted models) may be necessary before the riddle of consciousness can be completely solved.

From a clinical neurologic perspective, one should consider first alertness or arousability as a prerequisite for most other aspects of consciousness. Alertness depends on the ascending reticular formation’s activating role for functions of the rostral structures that perform tasks associated with and without conscious awareness. Next, we should consider awareness a multicomponent function that depends on an infrastructure of attention, allowing focusing of mental activity. Awareness of the outside world (for all but ollfaction) requires the parietal cortex for sensory processing and interpretation, after initial reception in the primary sensory areas. For sensory processing to be meaningful, it must be channeled into the limbic system through the temporal lobes, especially the amygdala. Connections with memory stores allow for appreciation of the relevance or importance of contemporary experiences. Motivation, self-awareness, and communications with the motor system relate to widespread integration of various cortical and subcortical regions. The frontal lobes serve an essential executive role in directing and maintaining attention and in planning behavior.

Consciousness is complex and represents more than the sum of its parts, but when disordered, it is best to resolve which components are affected. The term impaired consciousness is too vague to be clinically useful. In an individual case we need to know what aspects of consciousness are impaired (eg, alertness, attention, or various components of awareness) and to what extent they are affected.

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